PREFACE TO THE FIRST EDITION

This book is a little venture to remedy in part the difficulties which the Indian students preparing for University Examinations in Geology encounter. As a student and later as a college teacher I have constantly experienced great difficulties caused by the absence of any book on this subject suitable for Indian students. Most of the books on the subject are foreign, dealing with structures and features existing in foreign lands and scarcely there is any space for their Indian counterparts or any reference to these. Moreover these books being very costly are beyond the reach of average Indian students. My object in this book has been to describe and cite Indian examples as far as possible apart from describing the general principles involved in this branch of Geology and secondly to present these in a cheap volume. How far I have succeeded in this venture particularly with regard to the first idea, upon which the merit of the book will depend to a large extent, will be judged by the reception that it gets from those for whom it is written as well as from those interested in the teaching of Physical Geology of India.

*　　*　　*　　*

I am indebted to the Director, Geological Survey of India, for kindly supplying photographs for illustration and permitting the same to be printed in this book. My thanks are also due to my revered teachers, Prof. S. K. Roy and Prof. S. N. Mukherjee of the Presidency College, Calcutta, for kindly revising the manuscript and giving valuable suggestions for its improvement. I am also indebted to my students Sri D.K. Sen Gupta, Sri D.R. Budhia and Sri S.P. Gupta for helping me in various ways.... ... .

*　　*　　*　　*

St. Xavier's College,
Ranchi.
1st. July, 1950.

A. K. DATTA

PREFACE TO THE SECOND EDITION

The exhaustion of the copies of the First Edition of this book necessitated the publication of the Second Edition which has been thoroughly revised and considerably enlarged giving more and later informations.

I am indebted to each and every teacher of Geology in the different Colleges and Universities of India. But for their kind help this book would not have been so well received. I tender my heartiest thanks to them. It is my duty to express my gratitude in particular to Dr. S.C. Chatterjee (Patna), Dr. C. Mahadevan (Waltair), Prof. N.N. Chatterjee (Calcutta), Dr. Rajnath (Banaras), Prof. N.L. Sharma (Dhanbad), Dr. A.S. Kalapesi (Bombay), Prof. P.N. Mukherjee (Calcutta), Dr. S. Deb (Calcutta), Dr. R.C. Misra (Lucknow), Prof. T.N. Muthuswamy (Madras), Dr. K.P. Rode (Udaipur), Prof. L. Rama Rao (Bangalore), Prof. S. Roy (Calcutta), Prof. P. Dutta (Calcutta), Dr. S.N. Wakhalloo (Patna), Prof. S. Mukherjee (Calcutta), Dr. M.L. Misra (Banaras), Dr. G. Chiplonkar (Saugor), Prof. K. V. Kelkar (Poona), Prof. Muzafer Ahmed (Aligarh), Prof. G. Subba Rao (Jabbalpore), Prof. K. Sripada Rao Kilpady (Nagpur), Prof. N.K. Mukherjee (Banaras), Prof. R. Sawney (Jammu), Prof. S. Mukherjee (Ahmedabad), Prof. Habibur Rasul (Aligarh), Prof. K. C. Dubey (Saugor), Prof. N. C. Mithal (Jammu), Prof A. P. Jain (Patna), Prof. G. P. Srivastava (Ranchi), Prof. R. Verma (Ranchi), Prof. Umesh Chandra (Ranchi), Prof. Bholanath (Patna) and Prof. D. N. Ojha (Patna).

* * * *

St. Xavier's College,
Ranchi.
1st. June, 1957.

A. K. DATTA

PREFACE TO THE THIRD EDITION

The quick exhaustion of the Second Edition of the book, although comparatively of a small number of copies, speaks of its popularity which is due to the kind help of all Professors of Geology of the different Indian Colleges and Universites. I have received all help from the Professors whose names have been gratefully mentioned in the preface to the Second Edition and also from Dr. M.S. Krishnan (Director, Indian School of Mines and Applied Geology, Dhanbad) Dr. P.G. Dowie (Madras), Professor D.K. Chakravarty (Banaras), Dr. A. K. Dey (Cuttack), Dr. T. C. Bagchi (Kharagpur), Dr. R. N. Sukeswala (Bombay), Dr. J. M. Chowdhury (Gauhati), Dr. M. Srirama Rao (Jabalpur), Dr. M.M. Chatterjee (Calcutta), Prof. M. R. Srinivasa Rao (Bangalore), Dr. N. Satpathy (Cuttack), Dr. N. Kanungo (Cuttack), Dr. P. Ganju (Aligarh), Prof. G.N. Mathur (Udaipur), Dr. L. V. Agashe (Poona), Prof. Y. K. Agarwal (Dhanbad), Prof. T. Narsingham (Dhanbad), Prof. S. Chatterjee (Calcutta), Prof. T.C. Sinha (Chaibassa), Prof. V.N. Singh (Patna), Prof. R.C. Misra (Patna), Dr. S. Sarkar (Kharagpur), Dr. R. C. Sinha (Banaras), Dr. R. L. Singh (Banaras), Dr. T. Bhattacharya (Jadavpur), Prof. B. Mukherjee (Jadabpur), Prof. P. N. Hore (Jadavpur), Prof. R. L. Mehta (Jammu & Kashmir), Prof. G. P. Dubey (Saugor), Professor Anantharaman (Mysore), Prof. C. Naidu (Bangalore). Prof. D. Neogi (Kharagpur), Prof. A. Roy (Calcutta), Prof. B. Ali (Aligarh), Prof. R. Acharya (Cuttack), Prof. D. K. Sen Gupta (Kharagpur) and Prof. D. K. Sen Gupta (Kharagpur).

I offer my thanks and express my gratitude to each one of them and to the Director, Geological Survey of India for kindly supplying me a few more illustrative photographs with the permission to print them in my book. I also thank my student Asif Asraf for giving me a few photographs for illustration.

The Third Edition has been further revised, enlarged and illustrated and I hope it will also be well received by the professors and students of Geology.

St. Xavier's College,
Ranchi
1st June, 1958.

A.K. DATTA

PREFACE TO THE FIFTH EDITION

We are thankful to all professors of Geology in different colleges of India for their kind appreciation of our book Introduction to Physical Geology. We express our greteful thanks to the professors whose names we are proud to mention in the preface to the earlier editions of the book and further to Prof : L. Suryanarayana (Vizianagram), Prof : N. Natarajan (Karaikudi), Prof : B. N. Das (Sundergarh), Prof: R. N. Misra (Sundergarh), Prof. N.K. Acharya (Cuttack), Prof. A. Prakash (Ranchi), Prof. Padmanavan (Dharamsala)., Prof. P. Misra (Dharamsala), Prof. N. P. Subramanyam (Guntur), Prof. P. Mahadev (Karikudi), Prof R.B. Bansode (Indore), Prof. S. Imam (Ranchi) and Prof. S.K. Bose (Calcutta).

We hope the new Edition will also be kindly received by the Professors as well as by the students of Geology in India.

Ranchi
1st. June, 1960

S.K. DATTA

Extracts of opinion of Professors of different Indian Universities on Introduction to Physical Geology by A.K. Datta.

I

1 *From* **Dr. S. C. Chatterjee, D.Sc., P.R.S. (Cal.), F.N.I., J.N.** Tata Professor of Geology, Patna Universiiy—
"I have great pleasure in writing a few words in appreciation of Prof. A.K. Datta's book "Introduction to Physical Geology". The book covers the syllabus in Physical Geology up to the degree standard. Its language is simple and the expression is lucid. Within as mall compass it deals adequately with all the fundamental principles of the subject. The most notable feature of the book which makes it indispensible to the Indian students is that it teems with typical landscapes and geomorphological features. I unhesitatingly recommend the book to our degree students..."

2 *From* **Dr. C. Mahadevan, M.A., D.Sc., F.A.Sc., F.N.I.,** Professor and Head of the Geology Department, Erskine College of Natural Science, Andhra University, Waltair—
"I have skipped through the book and find that it is drawn up excellently and its Indian example is a very special feature to commend itself as a suitable book for the B.Sc. students and for those taking Geology in Engineering and Agricultural courses......I congratulate you on the production of this book. The illustrations are indeed very good"

3 *From* **Dr. A. S. Kalapesi, D.Sc.,** Formerly Professor of Geology, St. Xavier's College, Bombay—
"It is a very interesting book well written with ample examples and illustrations from India. I appreciate your efforts to make it intelligent as well as useful to our Indian students. It is high time that we should have such books written by experienced teachers giving as much information from Indian standpoint of view. To a beginner or to one who takes interest in this subject, it is a simple and useful book as it gives a general idea of all the branches of Geology—specially a short account of minerals and rocks. Photographs and figures are well selected and clear and nicely printed. The diagrams are also well chosen and quite accurately done. The selection of the subject matter and its limitations are such as can be best decided by a teacher only and I think you have taken the correct and proper estimate and view from a student's standpoint. I congratulate you on producing such a book at a time when the subject is coming in front line"

4 *From* **Prof. P.N. Mukherjee, M.Sc. (Lond.), D.I.C. (Lond.),** M.M.G.I., Formerly Geologist, G.S.I. and Head of the Department of Geology, Ashutosh College, Calcutta—

"I read your book 'Introduction to Physical Geology' with great interest. We were surely very badly in need of such a book for a long time, as there is none like this for junior students. The most interesting feature of the book is the description of some of the Indian examples of Physical Geology so useful to the Indian students. This book would undoubtedly give great help to those preparing for the I.Sc. and B.Sc. examinations in Geology. I am sure there would be a great demand for such a book."

5 *From* **Dr. K.P. Rode, M.Sc., Ph.D. (Zurich),** University Department of Geology, University of Rajasthan, Udaipur—

"I congratulate you heartily on the attempt you have made in writing this book on Indian Physical Geology wherein our students, both of Geology and Geography can now read with lively interest as you have given all Indian examples"

6 *From* **Prof. T.N. Muthuswamy,** M.A,, F.A.Sc., Professor of Geology, Presidency College, Madras—

"I went through the book and think it very useful to B.Sc. students"

7 *From* **Dr. R.C. Misra, Ph.D.,** F.G.M.S., Geology Department, Lucknow University—

"I congratulate you on this attempt which was long overdue from Indian teachers"

8 *From* **Dr. G.W. Chiplonkar,** D.Sc., Department of Geology, University of Saugor—

"A book on this subject to meet the requirements of Indian students was very much needed and I am glad that you come forth with a book of that kind, on doing which kindly accept my congratulations"

9 *From* **'Science and Culture',** October 1950—

"Students interested in the science of the earth in this country, would very much welcome books of this nature, which deal principally with all the forces of Dynamical Geology that shape the face of the earth.

... ...

The book would thus be useful to the students of the Intermediate science classes and also to B.Sc. pass course students of the Indian University. Non-geologists who are interested to know about the natural phenomena such as earthquakes, volcanoes, glacier etc. of this country would also be very much benefitted by this book"

1 *From* **Dr. M. S. Krishnan,** Formerly Director Geological Survey of India and Director, Indian School of Mines and Applied Geology, Dhanbad :
"It is a good attempt to present the subject to the junior classes with examples taken from India".

2 *From* **Dr. P. C. Dowie,** Chief Professor, Department of Geology, Presidency College Madras :
"Introduction to Physical Geology by Professor A. K. Datta is an excellent book on Elementary Physical Geology for University students. The author has presented clearly and in simple language the fundamentals of the subject with Indian examples wherever possible. I have no hesitation in recommending it for the First Year B.Sc. students in Geology. It is also reasonably priced so as to be within the reach of students of average means".

3 *From* **Dr. T. C. Bagchi,** Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur :
"I have gone through your book Introduction to Physical Geology. I appreciate very much your effort for the production of a book on Physical Geology with Indian examples. The book has met the long felt need of Indian students and I congratulate you on the attempt".

4 *From* **Dr. R. N. Sukeswala,** Head of the Department of Geology and Geography, St. Xavier's College, Bombay :
"I have looked into your book. I find that it is a book written well in simple language covering the important topics for the students of Physical Geology. It is gratifying to note that the general get up of the book is what would have been desired.

Your attempt to quote Indian examples wherever possible is pariseworty".

5 *From* **Dr. J.M. Chowdhury,** Head of the Department of Geology, Gauhati University :
"We have recommended the book to the B.Sc. Students. It has been found to be very useful and illustrative and as most of the examples are from Indian localities, the students will also find the book quite interesting".

6 *From* **Dr. M. Srirama Rao,** Professor of Geology and Head of the Department, Mahakoshal Mahavidyalaya, Jabalpur :
"I have gone through your book Introduction to Physical Geology and find it interesting and nicely illustrated. I congratulate you on bringing out such a work that fills the need of the graduate students of India".

7 *From* **Prof. M. R. Srinivasa Rao,** Central College, Bangalore : "I have received your book Introduction to Physical Geology and I have no hesitation in saying that it is an ideal text book for the I. Sc. and B. Sc. students".

1 From Dr. M. S. Krishnan, Formerly Director, Geological Survey of India and Director, Indian School of Mines and Applied Geology, Dhanbad:
"It is a good attempt [illegible] with examples taken from India".

2 From Dr. [illegible] Chief Professor, Department of Geology, Presidency College, Madras:
"Introduction to Physical Geology by [illegible] [illegible] for the University students. The [illegible] and in simple language the [illegible] with Indian examples [illegible] is recommended [illegible] of Geology. It [illegible] the needs of students of [illegible]".

3 From Dr. [illegible] Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur:
"I have gone through your book Introduction to Physical Geology. I appreciate [illegible] for the introduction of a book on Physical Geology with Indian examples. The book has met the long felt need of the students and I congratulate you on the attempt".

4 From Dr. B. S. [illegible], Head of the Department of Geology and Geography, M. S. [illegible] College, Bombay:
"I have looked into your book. I find that it is quite well written in simple language covering the essential topics for the students of Physical Geology. [illegible] to note that the [illegible] of the book is what would have been expected.
Your attempt to quote Indian examples wherever possible is praiseworthy".

5 From Dr. [illegible], Head of the Department of Geology, Gauhati University:
"We have recommended the book to the B.Sc. Students. It has been found to be very [illegible] and illustrative and [illegible] Indian localities [illegible] the students also find the book quite interesting".

6 From Dr. M. [illegible] Rao, Professor of Geology and Head of the Department, [illegible] Maharaja's [illegible]:
"I have gone through your book Introduction to Physical Geology and find it interesting and nicely illustrated. [illegible] for bringing out such a work that fills the need of the graduate students of India".

7 From Prof. M. R. Srinivasa Rao, Central College, Bangalore:
"I have received your book Introduction to Physical Geology and I have no hesitation in saying that it is an ideal text book for the I. Sc. and B. Sc. students".

CONTENTS

INTRODUCTION
TO
PHYSICAL GEOLOGY

CHAPTER I

INTRODUCTORY

Geology defined

The word *Geology* has been derived from the Greek words *Ge* meaning the *earth* and *logos* meaning *discourse*. Geology is therefore the science of the earth.

Branches of Geology

The subject of Geology is divided into several branches which are as follows :—

(1) *Physical Geology*—It deals with the geological processes which bring about changes upon the earth's surface. This includes :—

(a) *Structural or Tectonic Geology*—It deals with the different kinds of structures produced in the crust of the earth as a result of the tectonic movements of the earth's crust.

(b) *Dynamical Geology*—This deals with the agencies, both inside and outside, which tend to bring about changes upon the earth's surface.

(c) *Physiographical Geology or Geomorphology*—This deals with the surface features of the earth or its topography.

(2) *Mineralogy and Petrology*—They deal with minerals and rocks respectively. The study of minerals (Mineralogy) includes the study of mineral formation, mineral association, mineral analysis, the study

of crystals and their formation. Petrology includes the study of rocks, their formation, their association etc.

(3) *Historical Geology*—It deals with the chronological changes brought about on the surface of the earth. It includes the study of—(a) *Stratigraphy*—dealing with the succession of rock formation and (b) *Palaeontology*—dealing with the relics of ancient animals and plants called fossils. (The word fossil has come from the Latin verb 'fodere' which means 'to dig'. So formerly the word fossil used to mean anything that was dug out. But then many minerals and rocks come under the usage of the term and hence later on the use of the term fossil was restricted to the organic remains preserved naturally. Hence fossils refer to the remains, or traces even, of animals and plants preserved in nature. These remains and traces are of the animals and plants which are mostly extinct now but some may have present-day descendants. The term also includes prehistoric finds of human activity.)

(4) *Economic Geology*—It deals with the utility of the study of geology and the practical application of the knowledge of geology.

Scope of Geology

A geologist is indispensable for the successful development of a mining industry. As a prospector and as an adviser for the fullest utilisation of an ore body, his advice is always sought. Not only in the field of mining and metallurgical industries, but also in the field of Engineering, geologists are to be consulted. Geologists help in the construction of dams, railway alignments, tunnels, construction of buildings in earthquake-shaken areas and in water prospecting including the selection of sites for water supply such as tube wells or ordinary wells. In problems of water supply, drainage and irrigation the advice of a geologist is indispensable.

Even in the field of public health he has much to contribute. In Europe the spas and other mineral springs which have been discovered by geologists and the waters of which have been tested by them, have been subsequently developed into health resorts. The waters of such spas have been largely used as remedy for the skin diseases, gout and rheumatism. Silicosis in miners has been traced by geologists to be due to their inhalation of minute particles of mineral matters. In the detection of adulteration of food matters by such mineral products as china clay and the like, and in the dust control of cities and towns, a geologist has much to contribute. In the analysis of drinking water and in the examination of water-bearing strata a geologist has a special field, as the excess or deficiency of any mineral matter in the drinking water is injurious to the human system. For instance, in an English town the calcium deficiency of children was found out by geologists to be due to the poor percentage of calcium in the drinking water which was again due to the low content of calcium in the water-bearing country rock of the place.

CHAPTER II

ORIGIN AND AGE OF THE EARTH

The earth being a member of the solar system, the origin of it is intimately connected with that of the solar system. There are many ideas to account for the origin of the solar system. Different scientists have tried to propound hypotheses on observation of the phenomena concerning the solar system and in their attempt to explain them.

Nebular Hypothesis by Kant

The earliest of the hypotheses for the origin of the universe is that of Immanuel Kant, the Prussian philosopher (in 1755). Newton has by that time propounded the Law of Gravitation. This Law has great influence on the hypothesis of Kant and later on that proposed by Laplace, the French mathematician (in 1796). According to Kant the solar system has evolved from a nebular mass. *Nebula* can be seen at night like white pieces of cloth in parts of the sky. They are mainly gaseous, though in places there may be clots of stars. Some of them are luminous and others are dark.

Kant proposed that the different parts of the nebula, out of which this solar system originated, at first moved in different directions at different speed. In course of time this nebula became a hot spinning one due to the concentration of the velocities in one definite direction. In its revolution through space this nebula began to radiate heat and as a consequence this gaseous nebula began to contract. This caused an increase in revolution and hence centrifugal force began to operate more and more. If any pliable sphere were revolved round its axis, its polar regions would get flattened and the equatorial region would be bulged and the sphere would assume an orange-like figure. This revolving gaseous nebula also assumed a similar figure. Gradual increase in the rate of revolution due to gradual contraction caused the separation of several rings from the equatorial region and these rings in time condensed to form planets. The planets, before solidification, would form satellites in the same manner. Such, in brief, is the history of the solar system as proposed by Kant. But Kant did not propose anything as to the ultimate origin of the nebular mass. This, he thought, was created in some supernatural ways.

Kant's hypothesis can not stand the attack of the Principle of Conservation of Angular Momentum which states, if no external forces are acting in a system the angular momentum remains the same and no interaction between the different parts can change its total amount of rotation. The idea, that rotation in a definite direction would be caused by the collision of the nebular matter, is unacceptable.

Nebular Hypothesis by Laplace

After Kant came Marquis de Laplace, the French mathematician. In 1796 he supported Kant's hypothesis after some modification. He assumed that the nebula was already a hot and rotating one. Then the history is much the same as that of the hypothesis of Kant. Thus he saved his hypothesis from the attack of the Principle of Conservation of Angular Momentum.

Laplace's hypothesis was able to explain that the planets are revolving round the sun in one plane nearly in their orbits. They are all rotating in the same direction from west to east. Almost all the satellites are also moving round the planets in the same way, and their orbits are slightly elliptical.

There is, however, one difficulty with this hypothesis. It is found that 98% of the total angular momentum of the entire solar system is distributed in the four major planets, although they contain less than 1/700 of the total mass, whereas the sun is contributing only 2% of the total angular momentum although it has over 99% of the total mass. If the outer part of the nebula had so much angular momentum, it could not have formed the solar system because condensation would not have been possible. So in the words of Spencer-Jones 'the origin of the solar system must be sought in the swift catastrophic action of the forces from outside.'

Planetesimal Hypothesis by Moulton and Chamberlin

After this Moulton in 1901 and Chamberlin in 1905 proposed the Planetesimal Hypothesis. They thought that the sun was wandering through space when a much larger star came so near the sun that little fragments were thrown off from the solar surface. The little fragments later aggregated to form planets and satellites. Hence these fragments are called planetesimals. The propounders thought that these planets were solid throughout but to Jeffreys they were first gaseous and then changed to liquid and finally to the solid state.

Jeffreys has shown that even if the existence of the solid planetesimals might be granted, they would soon go into the gaseous state by the heat generated by their mutual impacts.

Tidal Hypothesis by Jeans and Jeffreys

After this Jeans in 1919 and Jeffreys in 1929 propounded their Tidal Hypothesis. This hypothesis like the previous one assumes a biparental origin of the solar system. It states that a huge star while moving through space came near the sun and raised tides upon the sun just as the sun and the moon cause tides on the surface of the oceans. As the star drew nearer, a filament was thrown off from the sun which ultimately formed the planets. The planets under the attraction of other planets as well as that of the sun produced satellites of their own. In this way the whole solar system came into existence.

The modification of Jeffreys was an actual lateral impact with the sun and the invading star. It should be remembered that the idea of such an actual collision with the sun was first proposed by Buffon about two hundred years ago.

This hypothesis is reasonable and is now the prevailing one for the origin of the solar system. Though it has undergone some criticisms, it is able to explain most of the observed solar phenomena.

The distribution of angular momentum per unit mass of the invading star, the sun and the planetary system goes against the idea.

Double Star Hypothesis by Lyttleton

The Double Star Hypothesis was put forward by Lyttleton in 1938. According to his idea the sun, before the origin of the solar system, had a companion star at some distance. Later an invading star came very close to these double stars and captured the companion star of the sun and receded away. The filament drawn by the attraction of the invading star came into the control of the sun which later gave rise to the planets and satellites in much the same way as explained by the tidal hypothesis.

Weizacker's Hypothesis

The difficulties arising from the distribution of mass in the solar system as faced by the nebular hypothesis of Laplace were tried to be solved by Weizacker in 1943 by assuming that the original gaseous envelope round the sun was having a much larger quantity of hydrogen and helium which had dissipated into space in course of time. The materials that formed the planets were carried in floating condition as dust particles in the rotating gaseous envelope round the sun. When two such particles of equal mass collided with each other they broke to pieces but when a big particle collided with a smaller one the two united to form a bigger mass. This sort of aggregation led ultimately to the formation of planets.

Meteoric Hypothesis by Schmidt

Recently Dr. O. J. Schmidt has proposed a new idea known as the Meteoric Hypothesis. This idea depends upon the fact that at the central region of our galaxy there are some foggy matter which may be some meteoric matter. Schmidt proposes that during its passage near the centre of gravity of the galaxy, the sun attracted some such meteoric substance which began to revolve round the sun in one direction. Those particles, moving in the same direction would ultimately unite to form bigger planets and satellites in much the same way as what the planetesimal hypothesis proposes. Though this hypothesis is still in its experimental stage, yet it can explain well some of the observed phenomena relating to the solar system.

G. Kuiper's Hypothesis

In 1951 G. Kuiper tried in another way. His hypothesis states that the stars after their birth from the nebular mass, became in course of evolution, hot and rotating ones. At last due to the internal temperature and pressure majority of them broke to form double or triple stars. In the case of our sun conditions were such that it formed the nucleus of a rotating disc of cloudy matter, which with more and more rotation produced flattening and formed some whorls of matter under the action of gravity. These whorls collided and united to form bigger masses which were the planets. Smaller ones formed satellites.

Condensation of the Earth

After the formation, the earth, like all other planets, began to move round the sun in an elliptical orbit. While wandering through space, the earth began to cool by radiating heat. The outer surface being at lower temperature internal heat began to be transferred by means of conduction, convection as well as by gas emanation. As a result of continued cooling, the surface gases began to be changed into the liquid state. The first one to be cooled was that which had high vaporisation temperature. The liquid, thus formed being denser tended to go down but while sinking it came in contact with the increased temperature below as a result of which it was again vaporised. Hence it again came up and thus there was a transfer of central heat to the surface. Again there was the formation of liquid, again it sank down and again it was vaporised and came up. This process went on until there began the accumulation of liquid at the centre of the earth. Heat developed from various sources, like chemical changes, latent heat, radio-active disintegration etc. retarded the progress in cooling but ultimately the whole of the gaseous earth was transferred into a liquid state.

In the liquid state the materials were arranged according to their density and thus there developed a density stratification in the interior of the earth, with the heaviest at the centre and lightest on the top, near the surface. This is evident from the study of seismology (vide Chapter XVI Interior of the Earth).

Change from the Liquid to the Solid State

The loss of heat, by radiation, was going on from the surface of the earth and the outer liquid began to solidify. Being heavier the solidified material tended to sink down and by a repetition of the same process, the outer liquid layer became solidified. This retarded the transfer of internal heat, and differentiation into acidic, intermediate and basic type of rocks was effected. The lightest rock material accumulated at the top and within it the radio-active elements were also concentrated. The volatile constituents also tended to keep the material liquid. Hence change of liquid to the solid state of the earth was very slow. The outer crust became cystalline in due course and the substratum was vitreous. In this way the solidification of the earth was effected.

Origin of Continents and Oceans

The change of state of the earth from the gaseous to the liquid and from the liquid to the solid brought with it the contraction of the earth in volume as a consequence of which wrinkles were developed on the surface. When the earth was sufficiently cool to hold water, water-vapour of the atmosphere condensed to form water and this collected in the depressed portions of the earth's surface to form oceans. The outstanding portions remained as land.

According to Sollas the origin of continents and oceans is due to unequal pressure of the atmosphere on the earth's surface when it was in the liquid state. Chamberlin, the author of the Planetesimal Hypothesis, thinks that the earth's surface, formed by the accumulation of the planetesimals, would be low in some places and high in others forming the ocean basins and continental parts. Lapworth suggested the phenomenon of folding as the cause for the formation of land masses and ocean basins. The anticlines of such folds would correspond to the land masses and the synclines to the ocean basins. This idea has also been supported by Love from physico-mathematical consideration.

Lowthian Green presents a tetrahedral form for the earth

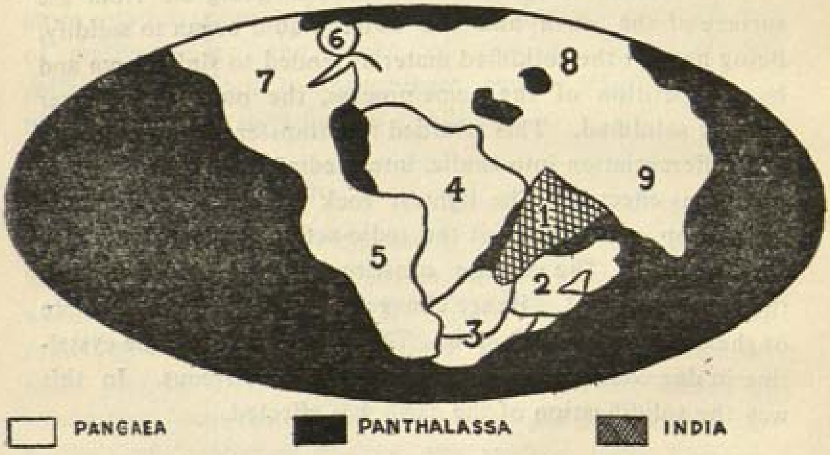


Fig 1

1 India. 2 Australia. 3 Antarctica. 4 Africa. 5 South America 6 Greenland. 7 North America. 8 Europe. 9 North Asia (according to Wegener's idea)

with faces corresponding to the ocean units. Though this has been supported by J. W. Gregory from geographical considerations, it has not been accepted as the tetrahedral form will change into a spherical form in the case of a rotating body.

According to Osmond Fisher the Pacific Ocean has been formed as a result of the detachment of the moon from the earth. It has not been accepted because the volume of the moon is much greater than that of the Pacific Ocean.

In whatever way they might have been originated, these small land portions later formed a vast continent called *Pangaea*. It was surrounded by a vast ocean called *Panthalassa*. The stratification of the crust and the fossils therein support the idea of such a continent. This continent later drifted to form the present continents and the water of the Panthalassa got into them to form the present oceans.

Two sets of opinion are current for the breaking up of the Pangaea. One is that the contraction due to condensation produced great rifts in the earth's crust and thus the Pangaea broke.

The other postulates the drifting of the parts of the Pangaea for the formation of the continents. The drifting of continents is largely due to the researches of Alfred Wegener. According to him, similarity in stratification, fossil content and the strike of the mountains on the opposite shores of the Atlantic Ocean suggests that once South Africa and South America were in one and the same continent. Further the western coast of South Africa and the eastern coast of South America more or less fit with each other supporting the view. According to Wegener a westward force and an equatorward force caused the drifting and the present configuration of the continents resulted in this way. The equatorward drift of Asia caused the formation of the Indian Ocean and the westward drift of the Americas produced the Atlantic Ocean.

Age of the Earth

The age of the earth has been tried to be determined from the evolutionary changes of animals, the rate of formation of stratified (sedimentary) rocks, the salinity of sea-water, the rate of cooling of the earth and the disintegration of radio-active elements.

Evidence from the evolutionary changes of animals—When the earth cooled down to be habitable, life appeared on it. The first formed animals were unicellular, i.e. composed of one cell. Later multicellular life with more complexities appeared in course of evolution. At first living beings were invertebrate, i.e. without any back-bone, and there were no hard parts in their bodies. For this reason they left no remains of their bodies to be preserved as fossils. Later animals with hard parts evolved and left remains to be preserved as fossils. The wonder of evolution is the appearance of man with brains. A rough estimate of the age of the earth can be made from the evolutionary development from unicellular organism to man. Biologists have determined the age of the earth to be 1,000 million years in this way. It is to be remembered that life appeared much after the origin of the earth and the age so determined is only a fraction of the real age of the earth.

Evidence from the rate of formation of sedimentary rocks—After the formation of the crust of the earth and the origin of continents and oceans, the denuding action on the land masses began by the agents like rain, wind etc. The sediment, thus formed, began to be collected on the ocean floors or in lake basins. This action is still to be seen at the mouth of the rivers like the Ganges, the Brahmaputra, the Nile etc. Uptill now nearly half a million feet of sedimentary rocks have been formed. Now if the annual rate of formation of these sedimentary rocks can be determined, the age of the earth can be calculated. The average rate of deposition of sediments and the total thickness of sedimentary beds have been taken to be one foot in 880 years and 5,14,000 ft. respectively, whence the age of the earth comes to be 400 million years. Metamorphic rocks formed from the most ancient sediments are 1,500 million years of age nearly.

Evidence from the salinity of sea water—Rivers bring with them a huge quantity of salts like sodium chloride, calcium chloride etc. in solution and pour them into sea. The sea water hence gets saline and the salinity increases every year. Now the total quantity of salt in the ocean can be determined from the total volume of the ocean water and the content of salt per unit volume, both of which can be determined. The yearly rate of increase of salinity can also be determined from direct observation and records. From these two data the age of the earth can be determined, at least from after the origin of oceans. From a determination of sodium and calcium salts in seawater the age of the earth has been determined to be 120 million years.

Evidence from the rate of cooling of the earth—From the rate of cooling of the earth Lord Kelvin determined the age of the earth to be between 20 to 400 million years. His determination of the age of the earth can not be accepted as he left out of consideration the radio-actively generated heat. Moreover the solar radiation of heat and the condition and ability of the sun to radiate heat might not have been the same always.

Evidence from the disintegration of radio-active elements—This is the most modern method of determining the age of the earth. There are certain elements like Uranium, Radium, Thorium etc. which spontaneously disintegrate rays and are changed to some other elements. Their final product is a variety of lead. Lead with atomic weight 206 is produced from Uranium, lead with atomic weight 208 is produced from Thorium and ordinary lead has an atomic weight of 207. Radium takes 1600 years to be half and Uranium takes a much longer period (4560 million years) to be so. Heat, pressure and chemical reaction have got no effect on their disintegration. From the determination of Uranium-Lead or Radium-Lead ratio in a rock body the age of the rock and hence, from it, the age of the earth can be determined. It is however to be borne in mind that no lead from other sources should come and mix with this radio-actively generated lead. This kind of determination has revealed that the most ancient rock on the earth (that containing Uraninite, from Huron Claim, Manitoba, Canada) is of the age of 1985 million years. As this rock occurs in a pegmatite cutting the country rocks, the invaded country rocks must be still older, probably over 2,000 million years. It is to be remembered that a great length of time elapsed before the formation of the rocks in the crust of the earth was possible. Hence from the above mentioned facts an imaginary estimate can be made about how old the earth is.

Stratigraphical Time Scale is shown in the following pages. Broad divisions of earth's history are called *eras*. Eras are divided successively into *periods* and *epochs*.

Eras	*Periods*	*Epochs*	*Notable physiographical events*	*Dominant animals*	*Dominant plants*	*Approximate age in million years*	*Climate*
1	2	3	4	5	6	7	8
Psychozoic (Reasoning life) or Quarternary. (*zoe* means life)		Holocene or Recent (with wholly) recent life)	Rise of civilization	Man	Modern Plants	0·015	Modern
		Pleistocene (with mostly) recent life	Periodic glaciation separated by warm interglacial period	Man	Modern Plants	1	Cold to glacial
Cenozoic (Modern life) or Tertiary. (*Cenos* means recent)	Neogene	Pliocene (with most recent life)	Rise of the Andes	Mammals & birds	Flowering Plants	10	Cold
		Miocene (with less recent life)	Rise of the Alps	Mammals & birds	Flowering Plants	30	Moderate
	Palaeogene	Oligocene (with few recent life)	Rise of the Pyrrenes	Mammals & birds	Flowering Plants	40	Warm to Moderate
		Eocene (dawn of recent life)	Rise of the Himalayas	Mammals	Flowering Plants	50	Moderate to warm

1	2	3	4	5	6	7	8
Mesozoic (Medieval life) or Secondary (*Mesos* means middle)	Late Mesozoic	Cretaceous (from creta meaning chalk)	Marine transgression in Trichinopoly	Dinosaurs	Elms, Oats, Mapples etc.	125	Moderate & humid
	Early Mesozoic	Jurassic (from the Jura Mts)	Marine transgression in Cutch	Dinosaurs	Conifers, Ginkgoes, & Horse-tails	150	Warm & arid
		Triassic (from the threefold division of rocks of this epoch in Germany into Bunter, Muschelkalk and Keuper)		Dinosaurs	Vegeta-tion not abundant	180	Warm & arid
Palaeozoic (Old life) Primary	Late Palaeozic	Permian (from Permia —an ancient kingdom near the Volga)	Major coal-bearing rock formation in India	Reptiles	Ferns	225	Moderate to glacial

1	2	3	4	5	6	7	8
		Carboniferous (from its coal formation)	Glaciation in the upper part in India.	Amphibeans	Ferns, Fern-like plants & club mosses	300	Glacial to warm at the end
	Middle Palaeozoic	Devonian (from Devonshire)		Fishes	Early land plants	350	Warm to Moderate
		Silurian (from Silures—an ancient tribe in Wales)		Fresh water fish and graptolites	Early land plants	375	Warm
	Early Palaeozoic	Ordovician (from Ordovices—an ancient tribe in Wales)		Graptolites	Algae	400	Moderate to warm
		Cambrian (from Cambria—the old name for Wales)	Rise of the Vindhya mountains in India.	Trilobites	Algae	500	Cold to Moderate

1	2	3	4	5	6	7	8
Proterozoic (early life)	Algonkian		Rise of the Aravalli mountains. Formation of Purana rocks—Cuddapah & Vindhyan deposits in India.	Protozoa		1,000	Cold at the end
Archaeozoic (Primitive life)			Formation of Dharwar rocks in India. Formation of Archaean rock system.	Age of larval life		1,500	
Eozoic (Dawn of life) (Eos means dawn)				Unicellular life			
Azoic (no life)			Initial development of the earth	No life			

CHAPTER III

COMMON MINERALS

Mineral defined

A *mineral* is a natural product formed by inorganic processes, which possesses a definite chemical composition and under favourable circumstances possesses a regular geometric shape which is an outward expression of its definite internal atomic structure. Artificial bodies produced in the laboratory are excluded from the list of the minerals. Though there must be a definite chemical formula there may be impurities and inclusions of foreign matter as well and amongst the members of a connected series there may be gradual transformation from one to the other in chemical composition, as in the case of plagioclase felspars.

Although a host of minerals are known in nature but practically a dozen covers the whole of mineral kingdom. These are the *rock-forming minerals* e.g. quartz, orthoclase etc. There is another class of minerals, which though negligible in relative abundance in the earth's crust, is very important from the economic point of view. They are *ore-forming minerals*. Suitable concentration of these minerals produces ore bodies out of which useful metals and other economic products are obtained, e.g. bauxite, chalcopyrite, hematite etc.

Identifying Characters of Minerals

Minerals may be identified by noting their physical properties as well as by chemical analysis and microscopic examination of them in thin slides. The physical properties inculde—(1) form, (2) cleavage, (3) fracture, (4) colour, (5) lustre, (6) streak (7) hardness and (8) specific gravity.

A mineral may also have any other special property peculiar to it only, e.g. magnetite is attracted by a magnet, galena marks paper etc. by which it can be identified. In the laboratory a mineral is examined in hand specimen by noting the above mentioned characters, while the examination under a microscope requires the preparation of a thin section. Minerals in microscopic sections show some characteristic properties and by noting them a mineral may also be identified. Mineral grains are also identified by microscopic study. Chemical analysis is also an aid to the purpose.

Form:—On the crystal development a mineral may show any one of the four forms—(a) Crystallised when showing well-formed big crystals. (b) Crystalline when showing smaller crystals not so well developed. (c) Crypto-crystalline when showing mere indistinct development of crystals which can be seen only from their thin sections under the microscope. (d) Amorphous—showing no crystal development at all.

Minerals may also show any one of the following descriptive forms :—

1 Granular—occuring in grains.
2 Friable—when the mineral mass breaks down by slight pressure.
3 Impalpable—When the grains are of extreme fineness.
4 Globular—showing an aggregate of small rounded masses.
5 Concretionary—showing an aggregate of bigger spherical bodies.
6 Nodular—when showing an aggregate of still bigger rounded bodies.
7 Pisolitic—when showing an aggregate of pea-like spherical masses.
8 Oolitic—when showing an aggregate of bodies resembling fish roe.
9 Botryoidal—when showing an aggregate of grape-like nodular masses.
10 Mammillary—when showing an aggregate of still bigger rounded masses.
11 Geoidal—when occuring as cavity-fillings.
12 Amygdaloidal—when occuring as almond-shaped cavity-fillings.
13 Nugget—when showing rounded bodies developed by rolling during transport.

14 Reniform—when showing kidney-shaped forms.
15 Lamellar—when showing thin leaf-like sheets.
16 Foliated, foliaceous or micaceous--when showing thin separable scale-like flakes.
17 Columnar or prismatic--when showing pillar-like masses.
18 Bladed—when showing an aggregate of masses resembling knife blades.
19 Fibrous—when showing an aggregte of fibres.
20 Acicular—when showing an aggregate of needle-like masses.
21 Capillary—when showing an aggregate of hair-like masses.
22 Filiform—when showingan aggregate of thread-like masses
23 Reticulated—net-like.
24 Stellated—star-like.
25 Dendritic—like the branches of a tree.
26 Tuberose—like the roots of a tree.
27 Radiating or divergent—branching from certain centre in more or less radius-like fashion.

Cleavage :—It is the property of easy fissility. Cleavage directions yield smooth surfaces on breaking. Cleavage may be termed—(a) perfect or distinct—when the broken surface is very smooth and fission is also very easy and, (b) imperfect or indistinct when the broken surface is not so smooth and fission is not so easy. If breaking is somewhat difficult and the broken surface is irregular then cleavage is absent. Non-crystalline minerals do not show any cleavage. Cleavage is also termed as cubic, rhombohedral, prismatic etc. according to the direction of breaking and shape of the broken piece.

Fracture :—The nature of the broken surface in any direction other than the cleavage direction will determine the fracture. It may be—(a) conchoidal when showing concave surface peculiar to conch shell, (b) uneven showing irregular surface, (c) even showing somewhat smooth surface, (d) hackly showing very much irregular surface, (e) splintery breaking in splinter-like parts.

Lustre :—It depends on the intensity of light reflection from the surface of the mineral specimen. Lustre of a mineral may be—(a) adamantine like that of a diamond, (b) resinous like that of resin, (c) pearly like that of a pearl, (d) metallic like that of a metal, (e) vitreous or glassy like that of glass, (f) silky like that of silk, (g) greasy like that of grease, (h) dull like that of earth. Other terms such as splendent, glistening, shining etc. qualifying the intensity of light reflection are also at times used in describing the lustre of a mineral.

Streak :—It is the colour of the powder of a mineral specimen left after rubbing it on a rough surface. Commonly mineral specimens are rubbed against unglazed porcelain plates. Generally streak shows the paler shade of the colour of the mineral although at times streak differs remarkably from the colour of the specimen.

Mohs' Hardness Scale

For testing the hardness of a mineral an arbitrary scale has been accepted which is called Mohs' scale of hardness (after the name of the propounder Mohs—a German mineralogist). In this scale there are ten minerals arranged in order of their increasing hardness and are marked serially from 1 to 10. The minerals are (1) Talc, (2) Gypsum, (3) Calcite, (4) Fluorite, (5) Apatite, (6) Orthoclase, (7) Quartz. (8) Topaz, (9) Corundum and (10) Diamond. Each mineral in the above scale will be scratched by all minerals with higher numbers.

Determination of the Hardness of a Mineral

Commonly a hardness box containing the above minerals (with the exception of diamond as it is very costly) is made and with the help of the minerals the relative hardness of an unknown mineral is determined by scratching the mineral to be tested with any mineral of the box. If a scratching is made on the mineral to be examined, the mineral is softer than the mineral of the hardness box. If on the other hand, the mineral of the hardness box is scratched then the hardness of the mineral (unknown) is greater than that of the mineral of the box.

Next the scratching is repeated with a mineral of greater or lower hardness, as is necessary, until no scratch is left on either of the two minerals. The hardness of the mineral is then equal to that of the box mineral. If any unknown mineral is scratched by any mineral of the hardness box, say 6, but is not scratched by the mineral 5, while the mineral 6, falls to power on the unknown mineral, then the hardness of the unknown mineral is intermediate between the two marks. In this way the hardness of a mineral is determined.

Precautions:—

(1) Fresh surfaces of minerals should be tried for hardness determination. Weathered surfaces give value less than the real one.

(2) Scratching should be done by the general surface of the specimens. Angular points or edges should be avoided.

(3) A real scratch mark should be distiguished from a chalk mark left by a softer mineral on a harder one. This can be done by blowing over the scratch mark or by gently rubbing it when a chalk mark will vanish but a scratch mark will persist and will present a groove cut on the mineral surface.

Specific Gravity

Specific gravity (Sp. gr.) of a substance is its relative density i.e., the ratio of the density of substance to the density of some standard substance. Commonly water is taken as the standard substance for the determination of the specific gravity of solids and liquids. The density of water at 4^0C (at which temperature water has the maximum density) is taken to be unit.

$$\text{Sp. gr.} = \frac{\text{weight of any volume of the substance}}{\text{weight of the same volume of water at } 4^0C}$$

We owe to the Greek scientist Archimedes for a ready method of determining the weight of the same volume of water as according to Archimedes a body completely or partially immersed in a liquid (or even a gas) apparently loses a part of its weight which is equal to the weight of the liquid displaced. A body when completely immersed in water will displace its own volume of water. Hence the apparent loss in weight of the body (i.e the weight of the body in air—the weight of the body when immersed in water) is equal to the weight of the same volume of water.

$$\therefore \text{Sp. gr.} = \frac{\text{weight of the substance in air}}{\text{weight of the substance in air—weight of the substance in water.}}$$

It is to be noted that although at the time of experiment, water is not likely to have the temperature of 4°C, but the difference in the value (from the real value) of the specific gravity obtained from water at the then room temperature is negligible.

There are various methods and instruments for determining the specific gravity of mineral substances. Commonly the sp. gr. of a mineral substance is determined in geological laboratories by Walker's steel yard balance. This is a steel yard balance working on lever principle and was invented by Walker.

Walker's steel yard balance consists of an iron stand supporting a steel yard divided into two unequal arms by the fulcrum point. The longer arm is graduated and the upper surface of the shorter arm is toothed and carries a heavy bob. The longer graduated arm moves up and down through a vertically rectangular slot fixed at the upper part of another iron stand. The slot carries a horizontal mark which marks the horizontal position of the steel yard necessary for complete equipoise.

The mineral specimen whose specific gravity is to be determined is fastened by a piece of thread and left hanging from the graduated arm and counter-balanced against the bob kept at a suitable position on the shorter arm. The reading on the graduated arm is noted. Let it be *'a'*. Then the specimen is completely immersed in water inside a beaker. Without disturbing the bob, it is again counter-balanced against the specimen immersed in water and the corresponding reading is taken. Let it be '*b*'.

As the instrument works on lever principle the readings, *a* and *b*, are inversely proportional to the weights of the body in air and water respectively.

As Sp. gr. $= \frac{W}{W-W_1}$, where W is the weight of the specimen in air and W_1 is its weight in water.

$$\text{Sp. gr.} = \frac{\frac{1}{a}}{\left(\frac{1}{a}-\frac{1}{b}\right)} = \frac{b}{b-a}$$

$$= \frac{\text{reading when the specimen is in water}}{\text{reading when the specimen is in water—reading when the specimen is in air.}}$$

The following precautions are necessary in the experiment:

(1) The bob should not be displaced for one set of readings (in air and water).

(2) The mineral specimen should be completely immersed in water and it should not touch the sides and bottom of the beaker.

(3) No air bubble should stick to the specimen. If there be any, it should be jerked off.

(4) For the second and subsequent pairs of readings water particles on the mineral specimen should be blotted off.

Crystals

Minerals sometimes form good crystals. A crystal is a regular geometric form bounded by several smooth surfaces. The regular shape is an expression of the internal atomic structure. In crystalline forms, the constituent molecules are nearly packed. There is also a definite pattern of their arrangement.

Non-crystalline forms (also called amorphous) lack in the closely packed arrangement. There is also another class which is called crypto-crystalline. In crypto-crystalline forms, the individual constituent parts have not yet attained the full crystalline state and their character is only discernible under the microscope.

Crystal Systems : Crystals are divisible into 6 divisions called systems. They are :

(1) *Isometric or Cubic System*—The crystals of this class possess three equal axes and all of them are at right angles to each other.

(2) *Tetragonal System*—The crystals of this system have three axes all at right angles to each other. Two horizontal axes are equal but the third vertical one is either shorter or longer.

(3) *Orthorhombic System*—The crystals of this system possess three axes all at right angles and all unequal.

(4) *Hexagonal System*—The crystals of this system have four axes, three equal horizontal axes cutting each other at 120^0 and the fourth vertical being unequl to the former three.

(5) *Monoclinic System*—The crystals of this system have three axes all unequal—one vertical, one horizontal and the third inclined to the vertical.

(6) *Triclinic System*—The crystals of this system prossess three unequal axes, all of which are inclined at some angles to each other.

DESCRIPTION OF MINERALS

(A) Rock-forming Group

(1) *Quartz*—Crystal system—Hexagonal. Form—Crystalline, massive, geoidal (as cavity-filling) or in grains (as in sand). Cleavage—absent. Fracture—uneven to conchoidal. Colour—generally colourless or white. Presence of impurities and inclusions impart various shades of colour, sometimes rosy (due to TiO_2), milky white, smoky (due to hydrocarbon compounds), brownish (due to iron) etc. Streak—uncoloured. Coloured varieties show paler colour in the streak. Luster—vitreous (like that of glass). Hardness—7. Sp. gr.—2·65. Crypto-crystalline forms show lower sp. gr.

(nearly 2·6). Amorphous variety shows still lower sp. gr. (nearly 2.2).

Composition—SiO_2 (Silicon Dioxide) Varieties—(a) Crystalline—Rock Crystal, Amethyst, Rosy Quartz, Smoky Quartz (Cairngorm Stone), Milky Quartz, Cat's eye, Aventurine. (b) Crypto-crystalline—Chalcedony, Agate, Carnelian, Plasma. Onyx, Flint, Hornstone, Lydian Stone, Firestone. (c) Amorphous—Opal, Hyalite.

(2) *Orthoclase*— (Potash Felspar). Crystal system—Monoclinic. Form—Commonly massive. Cleavage—perfect—two sets which are nearly at right angles. (The name has come from two Greek words—*orthos* meaning rectangular—and *clastos* meaning cleavage). Fracture—uneven. Colour—white, pink or gray. Streak—uncoloured. Lustre—vitreous Hardness—6. Sp. gr.—2·56.

Composition—K_2O, Al_2O_3 $6SiO_2$ (Potassium-Aluminium-Silicate.) Varieties—(a) Crystalline—Moonstone, Adularia, Sanidine etc.

(3) *Microcline*—Crystal system—Triclinic. Form—Commonly massive. Cleavage—perfect. Fracture—uneven. Colour—cream coloured or green. Streak—uncoloured. Lustre—vitreous. Hardness—6 (generally a bit harder than orthoclase). Sp. gr.—2·55 (generally a bit less than orthoclase).

Composition—K_2O, Al_2O_3, $6SiO_2$. (Potassium—Aluminium Silicate.)

(4) *Plagioclase*— (Soda-lime Felspars). This is another group of felspar minerals. The end members are Albite—Na_2O, Al_2O_3, $6SiO_2$ and Anorthite—CaO, Al_2O_3, $2SiO_2$. The intervening members are (after Albite) (i) Oligoclase, (ii) Andesine (iii) Labradorite and (iv) Bytownite.

The group characters are—

Crystal system—Triclinic. Form—commonly massive. Cleavage—perfect, two sets, which are nearly at right angles though not exactly. (The name has originated from two Greek words—*Plagios* meaning oblique and *Clastos* meaning cleavage). Fracture—uneven. Colour—white, gray or cream-coloured. Streak—uncoloured. Lustre—vitreous. Hardness—6—6·5 Sp. gr. – 2·6—2·76.

Composition—Silicates of Aluminium, Sodium and Calcium.

(5) *Pyroxene*—This is the name of another group of minerals like the felspars. The more important members are—(i) Enstatite (ii) Hypersthene (iii) Augite (iv) Diopside (v) Rhodonite. Crystal system—Orthorhombic (Enstatite and Hypersthene), Monoclinic (Augite, Diopside etc.) and Triclinic (Rhodonite etc.) Form—commonly massive, lamellar or granular. Cleavage—two sets, nearly at right angles. Fracture—uneven. Colour—black, dark-green or grayish. Streak—uncoloured to grayish or greenish. Lustre—vitreous. Hardness—5—6 Sp. gr.—3·2.—3·6.

Composition—Silicates of Calcium and Magnesium, sometimes also with Iron, Aluminium and Sodium.

(6) *Amphibole*—This is another group of minerals very similar to the pyroxene. In hand specimens it is very difficult to distinguish between the two groups.

The important members are—(i) Anthophyllite (ii) Tremolite (iii) Actinolite and (iv) Hornblende.

The group characters are—

Crystal system—Orthorhombic (Anthophyllite), Mono.-clinic (Tremolite, Actinolite, Hornblende etc.) and Triclinic (Aenigmatite). Form—commonly massive. Also fibrous or granular. Cleavage—perfect. Two sets inclined at angles of 124° and 56°. Fracture—uneven. Colour—black, green or grayish. Streak—uncoloured to grayish or greenish. Lustre—vitreous. Hardness—5—6. Sp. gr.—2.9—3.8.

Composition—Similar to the pyroxenes but with a little water.

(7) *Mica*—This is another group of minerals, the most important of which are muscovite, biotite and lepidolite.

(a) *Muscovite* (Potash mica)—Crystal system—Monoclinic. Form—flaky or scaly. Cleavage—perfect, one set, basal. Fracture—not easily obtainable due to good cleavage. Colour—colourless, grayish or pinkish. Lustre—pearly. Streak—

uncoloured. Hardness—2—2.5. Sp. gr.—2.76—3. The sheets, when thin, are flexible and elastic and produce percussion figures when pressed with hard and blunt rods.

Composition—Silicate of Aluminium and Potassium with water.

(b) *Biotite*—(Iron mica)—Crystal system—Monoclinic. Form—flaky or scaly. Thin sheets are elastic and flexible and produce percussion figures. Cleavage—perfect, one set, basal. Fracture—not obtainable easily due to good cleavage. Colour—black or dark green. Streak—uncoloured, often a bit greyish or brownish due to decomposition. Lustre—pearly. H—2.5—3. Sp. gr.—2.7—3·1.

Composition—Silicate of Fe, Al, Mg and K with water.

(c) *Lepidolite*—(Lithium mica)—Crystal system—Monoclinic. Form—in scales or in grains. Cleavage—perfect, one set. Fracture—not easily obtainable. Colour—pinkish or white. Streak—uncoloured. Lustre—pearly. H—2·5—4. Sp. gr.—2.8—3.3.

Composition—Silicate of K, Li, Al with water and Fluorine.

(8) *Olivine* — Crystal system — Orthorhombic. Form—massive or granular. Cleavage—imperfect. Fracture - conchoidal. Colour—green or yellowish green. Streak—uncoloured. Lustre—vitreous. H—6.5—7. Sp. gr.—3.27—3.37.

Composition—Silicate of Mg and Fe.

(9) *Garnet*—It is also a group of minerals including the following important members—(i) Grossularite—Ca-Al garnet. (ii) Almandite—Fe-Al garnet. (iii) Spessartite—Mn-Al garnet. (iv) Pyrope—Mg-Al garnet, (v) Andradite—Ca-Fe garnet.

The group characters are—Crystal system—Isometric. Form—granular often in good dodecahedral or traphezohedral crystals. Cleavage — absent. Fracture — conchoidal. Colour—red, black or green. Streak—uncoloured. Lustre—vitreous. H—7. Sp. gr.—3·2—4.3.

Composition—$3R''O, R_2'''O_3, 3SiO_2$ where R'' stands for Ca, Mg, Fe (ous) or Mn and R''' stands for Al, Fe (ic), Cr or Ti.

As Grossularite has the composition—$3CaO, Al_2O_3, 3SiO_2$.

(10) *Calcite*—Crystal system—Hexagonal. Form—crystals common. Also fibrous, granular, nodular, stalactitic and earthy. Cleavage—perfect (rhombohedral). Fracture—conchoidal but very difficult to get owing to the presence of good cleavage. Colour—commonly white or colourless. Also green, blue, red etc. Streak—white. Lustre—vitreous. H—3. Sp. gr.—2.7.

Composition—Calcium Carbonate—$CaCO_3$.

Varieties—Dog-tooth Spar, Nail-head Spar, Iceland Spar, Argentine, Stalactites, Stalagmites, Calcareous tufa, Limestone, Lithographic stone, Saccharoidal limestone, Marble, Chalk, Oolite and Pisolite.

(11) *Dolomite*—Crystal system—Hexagonal. Form—Commonly granular. Cleavage—perfect (rhombohedral). Fracture — uneven to conchoidal. Colour — commonly white, sometimes pinkish. Streak—white. Lustre—vitreous to pearly. H—3.5–4. Sp. gr.—2.8.

Composition — Calcium-Magnesium Carbonate — $CaCO_3$, $MgCO_3$.

(12) *Gypsum* — Crystal system — Monoclinic. Form—crystals often common. Also granular, fibrous or massive Cleavage;— perfect. Fracture — uneven. Colour — white, grayish white or pinkish white, Lustre—vitreous. H—2. Sp. gr.—2·3.

Composition—Hydrated Calcium Sulphate—$CaSO_4$, $2H_2O$.

Varieties—Selenite, Alabaster and Satin Spar.

(13) *Kyanite*—Crystal system—Triclinic. Form—bladed or columnar. Cleavage—perfect. Fracture—uneven. Colour—blue, bluish white, gray or green. Streak — colourless. Lustre—pearly. H—5—7. Sp. gr.—3.6.

Composition—Aluminium Silicate—Al_2O_3, SiO_2.

(14) *Silimanite*—Crystal system—Orthorhombic. Form—commonly in radiating needles or in fibrous aggregates. Cleavage—perfect. Fracture—uneven. Colour—grayish or brownish gray. Streak—white. Lustre—vitreous. H—6—7. Sp. gr.—3.2.

Composition—Aluminium Silicate—Al_2O_3, SiO_2.

(15) *Andalusite*—Crystal system—Orthorhombic. Form—in crystals, massive or granular. Cleavage—imperfect. Fracture—uneven. Colour—whitish, grayish or flesh red. Streak—colourless. Lustre—vitreous. H—7·5. Sp. gr.—3·1—3·2.

Composition—Aluminium Silicate—Al_2O_3, SiO_2.

(16) *Kaolin*—Crystal system — Monoclinic. Form — commonly earthy, easily falls to powder. Cleavage—perfect, basal. Fracture—uneven. Colour—white, grayish white or brownish white. Streak—white. Lustre—Commonly dull. H—2—2.5. Sp. gr.—2·6.

Composition—Hydrated Aluminium Silicate—Al_2O_3, $2SiO_2$, $2H_2O$.

(17) *Apatite*—Crystal system—Hexagonal. Form—crystals common. Sometimes granular or massive. Cleavage—indistinct. Fracture—uneven to conchoidal. Colour—generally bluish green. Streak—white. Lustre—vitreous. H—5. Sp. gr.—3.2.

Composition—Calcium Phosphate with either Calcium Chloride or Calcium Fluoride $3Ca_3(PO)_2$, $CaCl_2$ or $3Ca_3(PO_4)_2, CaF_2$.

(18) *Tourmaline* — Crystal system—Hexagonal. Form—prismatic, crystals common. Crystals sometimes slender or radiating. Also massive. Cleavage—imperfect, Fracture—uneven to somewhat conchoidal. Colour—commonly black also green, red or brown. Streak—uncoloured. Lustre—vitreous. H—7·5. Sp. gr.—3.

Composition—A complex Boro-Silicate of Aluminium with a little Magnesium, Iron and Alkali metals.

(19) *Beryl* — Crystal system — Hexagonal. Form—prismatic. Crystal—common. Also massive and granular. Cleavage—imperfect. Fracture—conchoidal. Colour—pale green, pale blue, yellowish or pinkish. Streak—white. Lustre—vitreous. H—7·5—8 Sp. gr.—2·7.

Composition—Silicate of Berylium and Aluminium, $3BeO$, Al_2O_3, $6SiO_2$.

Varieties—Emerald (pale green) and Aquamarine (pale blue).

(20) *Fluorite*—(Also called *Flour Spar*). Crystal system —Isometric. Form—cubic crystals common. Also granular or massive. Cleavage—perfect. Fracture—uneven to conchoidal. Colour—white with violet tinge sometimes. Lustre—vitreous. H—4. Sp. gr.—3·2.

Composition—Calcium Fluoride—CaF_2.

(21) *Zircon*—Crystal system—Tetragonal. Form—prismatic. Crystals—common, also granular. Cleavage—imperfect. Fracture—conchoidal. Colour—colourless, grayish or brownish. Streak—uncoloured. Lustre—adamantine. H—7·5 Sp. gr.—4·7.

Composition—Silicate of Zirconium—ZrO_2, SiO_2.

(22) *Corundum*—Crystal system—Hexagonal. Form barrel-shaped crystals, often rough, also massive and granular. Cleavage—absent. Fracture—uneven. Colour—common varieties show grayish or brownish colours. Ruby is red and Sapphire is blue. Streak—uncoloured. Lustre—vitreous. H—9. Sp. gr.—4.

Composition—Aluminium Oxide—Al_2O_3.

Variety—Ruby (red), Sapphire (blue), Oriental topaz (yellow), Oriental amethyst (purple), Oriental emerald (green) Emery (grayish black).

(23) *Topaz*—Crystal system—Orthorhombic. Form—prismatic, granular. Cleavage—perfect. Fracture—uneven to subconchoidal. Colour—faint yellow, white. Streak—colourless. Lustre—vitreous. H—8. Sp. gr.—3·5.

Composition—$(AlF)_2$ SiO_4 with a little water.

(B) Ore-forming Group

Aluminium Minerals :

(1) *Bauxite*—Amorphous. Form—granular, earthy, concretionary, oolitic or pisolitic. Cleavage—absent. Fracture—sub-conchoidal. Colour—grayish white or brownish white.

Streak—grayish or brownish white. Lustre—dull, earthy. H—2. Sp. gr.—2·5.

Composition—Aluminium Hydroxide—Al_2O_3, $2H_2O$.

Antimony Minerals :

(2) *Stibnite*—Crystal system—Orthorhombic. Form sometimes in acicular crystals, commonly radiating and massive. Cleavage — perfect. Fracture — uneven. Colour — blackish gray. Lustre—metallic. H—2. Sp. gr.—6·4.

Composition—Antimony Sulphide—Sb_2S_3.

Arsenic Minerals :

(3) *Realgar*—Crystal system—Monoclinic. Form—prismatic crystals frequent, commonly granular. Cleavage—indistinct. Fracture — sub-conchoidal. Colour — orange-red. Streak—orange-red. Lustre—resinous. H—1·5—2. Sp. gr.—3·5.

Composition—Arsenic Monosulphide—AsS.

(4) *Orpiment*—Crystal system—Monoclinic. Form—generally massive or foliated. Cleavage—perfect. Fracture—subconchoidal. Colour — lemon-yellow. Streak — lemon-yellow Lustre—resinous to pearly. H—1·5—2. Sp. gr.—3·4.

Composition—Arsenic Trisulphide—As_2S_3.

(5) *Arsenopyrite*—(Also *Mispickel*) — Crystal system—Orthorhombic. Form — prismatic crystals frequent, also massive. Cleavage — indistinct. Fracture — uneven, brittle. Colour—tin-white to steel gray, often tarnished to copper-red on exposure. Streak—grayish black. Lustre—metallic. H—5·5 Sp. gr. 6·1.

Composition—Sulpharsenide of Iron—FeAsS.

Barium Minerals :

(6) *Witherite*—Crystal system—Orthorhombic. Form—commonly massive or columnar. Cleavage—imperfect. Fracture—uneven. Colour — white or grayish. Streak — white. Lustre—vitreous. H—3·5. Sp. gr.—4·3.

Composition—Barium Carbonate—$BaCO_3$.

(7) *Barite*—(Also *Barytes*) —Crystal system—Orthorho-

mbic. Form — sometimes in tabular crystals, also massive, granular or fibrous. Cleavage—perfect. Fracture—uneven. Colour—commonly white. Streak—white. Lusture—vitreous H—3. Sp. gr.—4·5.

Composition—Barium Sulphate—$BaSO_4$

Bismuth Minerals :

(8) *Bismuthinite*—Crystal system — Orthorhombic. Form —commonly massive, fibrous, foliaceous or in acicular crystals. Cleavage—perfect. Fracture—uneven. Brittle. Colour —grayish black or shining white. Streak—same as colour. Lustre—metallic. H—2. Sp. gr.—6·5. Easily fusible.

Composition—Bismuth Trisulphide Bi_2S_3.

Chromium Minerals :

(9) *Chromite*—Crystal system—Isometric. Form—commonly granular also massive. Cleavage—absent. Fracture —uneven. Colour—black or brownish black. Streak—brown. Lustre—Sub-metalic. H—5·5. Sp. gr.—4·6.

Composition—Oxide of Iron and Chromium—FeO, Cr_2O_3.

Cobalt Minerals :

(10) *Cobaltite*—Crystal system—Isometric. Form—in crystals, granular or massive. Cleavage—perfect. Fracture —uneven. Colour—silver-white generally. Streak—grayish black. Lustre—metallic. H—5·5. Sp. gr.—6—6·3.

Composition—Cobalt Arsenide—$CoAsS$ or $CoAs_2, CoS_2$

Copper Minerals :

(11) *Chalcopyrite* — Crystal system — Tetragonal. Form— commonly massive. Cleavage—indistinct. Fracture—uneven. Colour—golden yellow (Hence also called fool's gold) Streak— greenish black. Lusture—metallic: H—3·5—4. Sp. gr.—4.2.

Composition—Sulphide of Copper and Iron—$CuFeS_2$.

(12) *Malachite*—Crystal system—Monoclinic. Form— crystals very rare. Commonly massive, botryoidal, fibrous or encrusting. Cleavage—indistinct. Fracture-conchoidal.

Colour—green. Streak—pale green. Lustre—often silky, otherwise dull. H—3·5—4. Sp. gr.—4.

Composition—Hydrated basic Carbonate of Copper—$CuCO_3$, $Cu(OH)_2$.

(13) *Azurite*—Crystal system—Monoclinic. Form—crystals rare. Commonly massive and earthy. Cleavage—indistinct. Fracture—conchoidal. Colour—deep sky-blue. Streak—pale blue. Lustre—vitreous to adamantine. H.—3.5—4. Sp. gr.—3·8.

Composition—Hydrated basic Carbonate of Copper—$2CuCO_3$, $Cu(OH)_2$.

Iron Minerals :

(14) *Pyrite*—(Also *Pyrites*). Crystal system—Isometric. Form—striated, cubic or pyritohedral crystals. Also massive, fibrous, reniform or granular. Cleavage—imperfect. Fracture—uneven to conchoidal. Colour—brass-yellow. Streak—greenish black. Lustre—metallic. H—6—6·5. Sp. gr.—5.

Composition—Iron Sulphide—FeS_2.

(15) *Hematite*—Crystal system—Hexagonal. Form—crystals commonly in tabular forms. Also reniform, botryoidal, scaly or foliaceous. Cleavage—indistinct. Fracture—uneven. Colour—steel-gray to brownish red. Streak—reddish brown. Lustre—metallic. H—5·5—6·5, Sp. gr.—5·2.

Composition—Iron Oxide—Fe_2O_3.

Varieties—Micaceous hematite, Specularite (scaly). Kidney ore, Martite (a pseudomorph of hematite after magnetite).

(16) *Magnetite*—Crystal system—Isometric. Form—crystals commonly octahedral. Also massive and granular. Cleavage—indistinct. Fracture—uneven. Colour—iron black. Streak—black. Lustre—metallic to dull. H—5·5.—6·5 Sp. gr.—5·1.

Composition—Iron Oxide—Fe_3O_4.

Varieties—Ordinary Magnetite and Lodestone.

(17) *Limonite*—Amorphous. Form—mammillary, botryoidal, fibrous, concretionary, earthy and massive. Colour—

brown. Streak—yellowish brown. Lustre—dull, sometimes silky. H—5·5. Sp. gr.—4.

Composition—Hydrated Iron Oxide—$2Fe_2O_3$, $3H_2O$.

(18) *Siderite*—(Also *Chalybite* or *Spathic Iron*)—Crystal system—Hexagonal. Form—crystals commonly rhombohedral. Often massive and granular. Cleavage—perfect. Fracture—uneven. Colour—ash-gray or brownish gray. Streak—white. Lustre—vitreous. H—3·5—4. Sp. gr.—3·8.

Composition—Iron Carbonate—$FeCO_3$.

Lead Minerals :

(19) *Galena*—Crystal system—Isometric. Form—cubic crystals common. Also massive and granular. Cleavage—perfect (cubic). Fracture—even to sub-conchoidal. Colour—lead-gray. Streak—lead-gray. Lustre—metallic. H—2·5. Sp. gr.—7·5.

Composition—Lead Sulphide—PbS.

(20) *Anglesite*—Crystal system—Orthorhombic. Form—in crystals, nodular or massive. Cleavage—imperfect. Fracture—conchoidal. Colour—commonly white or grayish. Streak—colourless. Lustre—commonly vitreous, sometimes adamantine. H—2·75—3. Sp. gr.—6·3.

Composition—Lead Sulphate—$PbSO_4$.

(21) *Cerussite*—Crystal system—Orthorhombic. Form—in simple twin or radiating crystals, massive or granular. Cleavage—distinct. Fracture—conchoidal. Colour—white or grayish. Streak—colourless. Lustre—commonly vitreous, sometimes resinous or even adamantine. H—3—3·5. Sp. gr. —6·4—6·6.

Magnesium Minerals :

(22) *Magnesite*—Crystal system—Hexagonal. Form—commonly massive, compact and earthy. Cleavage—perfect. Fracture—conchoidal. Colour—white, grayish white or brownish white. Streak—white. Lustre—vitreous. H—4—4·5. Sp. gr.—3.

Composition—Magnesium Carbonate—$MgCO_3$.

Manganese Minerals :

(23) *Pyrolusite*—Crystal system—Orthorhombic but usually occurs as a pseudomorph after manganite (Mn_2O_3, H_2O). Form—commonly massive, reniform or fibrous. Cleavage—absent. Fracture — uneven, brittle. Colour — iron-black. Streak—black. Lustre—metallic. H—2—2·5 Sp. gr.—4·8. It soils hand when touched.

Composition—Manganese Dioxide with a little water.

(24) *Psilomelane*—Amorphous. Colour—iron-black. Streak—brownish black. H—5—6. Sp. gr.—3·5—4·5.

Composition—Hydrated Oxide of Manganese, sometimes with a little of Barium, Sodium and Potassium Oxides.

Mercury Minerals :

(25) *Cinnabar*—Crystal system—Hexagonal. Form—commonly massive, granular or encrusting. Cleavage—perfect Fracture—uneven. Colour—reddish (intermediate between pink and scarlet). Streak—scarlet. Lustre—adamantine, dull in some cases. H—2—2·5. Sp. gr.—8.1.

Composition—Mercury Sulphide—HgS.

Molybdenum Minerals :

(26) *Molybdenite*—Crystal system—Hexagonal. Form—commonly massive, scaly, foliated or granular. Cleavage—perfect. Sectile (slices can be cut with a knife.). Colour—lead-gray. Streak—greenish lead-gray. Lustre—metallic. Feel—greasy. H—1—1·5. Sp. gr.—4·8.

Composition—Molybdenum Disulphide—MoS_2.

Nickel Minerals :

(27) *Millerite*—Crystal system—Hexagonal. Form—crystals commonly slender, usually radiating. Also in tufts like hair. Cleavage—perfect. Fracture—uneven. Colour—bronze yellow. Streak—greenish-black. Lustre—metallic. H—3—3.5. Sp. gr.—5.5.

Composition—Nickel Sulphide—NiS.

(28) *Niccolite* — Crystal system — Hexagonal. Form—

crystals rare, usually massive. Cleavage—absent. Fracture—uneven. Colour—reddish like copper. Streak — brownish black. Lustre—metallic. H—5—5·5 Sp. gr.—7·3.—7·6.

Composition—Nickel Arsenide—NiAs.

Silver Minerals :

(29) *Argentite*—Crystal system—Isometric. Form—crystals distorted, octahedral or cubic. Commonly massive or reticulated. Cleavage—indistinct. Fracture—sub-conchoidal. Colour—lead-gray (blackish). Streak—same as colour (shining). Lustre—metallic. H—2—2·5 Sp. gr.—7·3.

Composition—Silver Sulphide—Ag_2S.

Tin Minerals :

(30) *Cassiterite*—(Also *Tinstone*). Crystal system—Tetragonal. Form—crystal tetragonal. Also massive, granular and in alluvial deposits. Cleavage—indistinct. Fracture—uneven. Colour—black or brownish black. Streak—white or brownish. Lustre—adamantine. H—6—7. Sp. gr.—7.

Composition—Tin Dioxide—SnO_2.

Titanium Minerals :

(31) *Ilmenite*—Crystal system—Hexagonal. Form—tabular. Also massive, compact, granular or loose as sand. Cleavage—indistinct. Fracture—conchoidal. Colour—iron-black. Streak—black or brownish black. Lustre—sub-metallic. H—5—6 Sp. gr.—4·8.

Composition—Oxide of Iron and Titanium—FeO, TiO_2.

(32) *Rutile*—Crystal system — Tetragonal. Form — prismatic crystals, often in twins. Rarely massive and compact. Cleavage — indistinct. Fracture — uneven. Brittle. Colour — reddish brown or black. Streak — pale brown. Lustre—metallic. H—6—6·5. Sp. gr.—4·2.

Composition—Titanium Dioxide—TiO_2.

Tungsten Minerals :

(33) *Wolfram*—Crystal system—Monoclinic. Form—tabu-

lar, also massive and bladed. Cleavage—perfect. Fracture—uneven. Colour—reddish brown or brownish black. Streak—chocolate brown. Lustre—sub-metallic. H.—5—5·5 Sp.gr.—7·5.

Composition—Tungstate of Iron and Manganese—(Fe, Mn) WO_4.

Zinc Minerals :

(34) *Sphalerite*—(Also *Zinc Blende*). Crystal system—Isometric. Form—crystals commonly tetrahedral. Also massive, compact and rarely botryoidal or fibrous. Cleavage—perfect. Fracture—conchoidal. Colour—black, brown, rarely yellow. Streak—brownish or white. Lustre—resinous. H—3·5—4. Sp. gr.—4·1.

Composition—Zinc Sulphide—ZnS.

Native Elements :

(35) *Sulphur*—Crystal system—Orthorhombic. Form—crystals pyramidal. Also massive, encrusting and in powder. Cleavage—indistinct. Fracture—uneven. Colour—straw-yellow (lemon like). Streak—white. Lustre—resinous. H—1·5—2·5. Sp. gr.—2.

Composition—Sulphur—S.

(36) *Graphite*—(Also *Plumbago*). Crystal system—Hexagonal. Form—commonly foliated, scaly, granular or earthy. Cleavage—perfect (basal). Sectile. Colour—grayish black. Streak—same as colour. Lustre—metallic. H—1—2. Sp. gr. 2·1. Feel—greasy.

Composition—Carbon—C, but contains some impurities like Ferric Oxide and clayey material.

(37) *Diamond*—Crystal system—Isometric. Form—commonly in octahedrons, also in twins. Cleavage—perfect. Fracture—conchoidal. Colour–colourless, yellowish, bluish, grayish or black. Streak—none. Lustre—adamantine when cut, often greasy when fresh and uncut. H—10. Sp. gr.—3·52. Feel—greasy.

Composition—Carbon—C.

Varieties—Bort (gray diamond), Carbonado (black diamond), Ballas (diamond grains forming a round mass).

CHAPTER IV

COMMON ROCKS

Rocks are aggregate of minerals and are units of which the earth's crust is composed. They are pages upon which the earth's history is written and a study of them is essential for the proper understanding of the science of the earth. Rocks can be broadly divided into three main classes—(i) *Igneous*, (ii) *Sedimentary* and (iii) *Metamorphic*.

As already pointed out, the earth started its career in a state of burning gases. In its revolution through space it began to radiate heat and consequently began to cool. From the gaseous state the earth first passed into the liquid state and then into the solid state (at least on the upper surface). This solidified rock type is the *igneous* variety. The word *igneous* is derived from the Latin word *Ignes* meaning fire. This is because of the fact that such rocks are formed from the molten and heated liquid material. The molten rock material, together with the gas content, is called the *magma*. Igneous rocks are formed from the solidification of magmas.

When the surface of the earth sufficiently cooled to hold water, oceans and other areas full of water came into existence. From that time began the destruction of the upstanding masses by the different agencies of erosion. The products of erosion of all the denuding agents were brought to lakes, seas or oceans and by the consolidation of such sediments, *sedimentary* rocks were formed. This is about the first-formed sedimentary rocks. Later sedimentary rocks have been formed from sediments derived from other igneous, sedimentary or metamorphic rocks.

The igneous and sedimentary rocks later are subjected to heat and pressure accompanying crustal movements. The effect of these is to change the characters of the pre-existing rocks and in this way the *metamorphic* rocks result.

Detailed discussion of these rocks is given below.

Characters of the Igneous rocks :

These rocks have been formed by the solidification of very hot molten rock material called magma. Such rocks originate generally at depth but sometimes are formed upon the surface of the earth. Others are formed when their magmas are arrested in their upward ascent somewhere below the crust and solidify there. Upon this there have been recognised two distinct classes of igneous rocks—one *plutonic* or *abyssal* (*intrusive*) and the other *volcanic* (*extrusive*)

The plutonic rocks are those which have solidified at some depth below the surface of the earth. They are seen only after long-continued deep erosion. The environment and condition under which plutonic rocks solidify are quite different from those under which volcanic rocks solidify. Upon the crystallisation of plutonic rocks pressure acts and therefore the rate of cooling is slow and dissolved gases can not escape. This produces a coarse-grained or phaneritic texture. In the case of the volcanic rocks there is no effect of pressure and the gases also escape easily. This produces a high rate of crystallisation and a consequent fine-grained or aphanitic texture.

The demarcation line between these two groups is not always clear and commonly a third middle group is recognised. These are the *hypabyssal* rocks. As it is intermediate in its mode of origin between a plutonic and a volcanic rock, its character is also intermediate between the two groups. This type commonly shows a medium-grained texture.

Igneous rocks show a definite order of crystallisation. They commonly present an interlocking texture and a massive and hard appearance. They do not contain any fossil as the sedimentary rocks nor do they show any clear stratification like them, though at times the piling of lava flows, one after another, may produce a deceptive stratified aspect. The parallel arrangement of minerals peculiar to metamorphic rocks is also absent in the igneous rocks.

More Common Igneous Rocks :

Acidic. (1) *Granite*—The name is bacause of the well developed grains. It is the most common variety of igneous rocks in the continental sector. It is medium to coarse-grained and is generally light coloured. In composition the silica percentage is quite high (65—80 p.c.) and this puts the rock into the acidic group. Mineralogically granite consists essentially of quartz and felspar. Generally orthoclase is the variety of felspar present, though at times plagioclase may also be present. Micas, both muscovite and biotite, are frequent. Sometimes hornblende is also seen. Accessory minerals include magnetite, apatite etc.

Rhyolite is the volcanic equivalent of granite.

(2) *Pegmatite*—This type of rocks occurs as dikes and veins cutting across the country rocks. They are frequent in ancient rocks. Pegmatites are generally of granitic composition. During the late stage of crystallisation of a magma, the residual part becomes generally very rich in volatile matter, alkali and silica. The presence of volatiles and relative freeness from interference from too many minerals produce very big crystals. Commonly quartz, orthoclase and mica (both muscovite and biotite) are present and with them there is sometimes a host of accessory minerals, sometimes of great economic importance, like apatite, tourmaline, topaz, lepidolite, beryl, cassiterite etc.

Intermediate. (3) *Syenite*—The name has been derived from Syene in Egypt. It is also a medium to coarse-grained rock, very similar to granite at the first sight. The distinction between granite and syenite lies in their mineralogical and chemical composition. Mineralogically syenites generally do not contain quartz or very little of it. Chemically the silica percentage is lower (50—65%). Orthoclase is adundant. Plagioclase is frequent. So also hornblende. Pyroxenes are rare. Accessory minerals include elaeolite, nepheline, leucite, apatite, magnetite, mica etc.

Trachyte is the volcanic equivalent of syenite.

(4) *Diorite*—It is a medium to coarse-grained rock generally darker in colour than the preceding ones. It has a silica percentage of 50—65 (same as syenite). The distinction between syenite and diorite lies in the fact that the alkali percentage is lower in diorite whereas the calcium and ferro-magnesian minerals have greater percentage. Orthoclase is commonly absent while plagioclase is always present. Biotite, hornblende and pyroxene are also present to a more or less extent. Quartz is sometimes present as an accessory mineral.

Dacite and *Andesite* are the volcanic equivalents.

Basic. (5) *Gabbro*—It is a medium to coarse-grained plutonic rock of dark colour and low silica percentage (40—50%)- Plagioclases and pyroxenes are the important minerals in gabbro. Olivine is a common accessory mineral.

(6) *Dolerite*—It is the hypabyssal equivalent of the gabbro type of rocks. It is medium to fine-grained. Chemically they present the same composition as gabbro.

(7) *Basalt*—It is the volcanic equivalent of the gabbro type. It is the most common volcanic rock. Basalt is fine-grained in texture and dark in colour. Chemically it contains lime-rich plagioclases and pyroxenes as the primary minerals. Accessory minerals include olivine, iron ores, sphene, ilmenite, leucite, nepheline etc. Trap (derived from the Swedish word *trapf* meaning stair) is a general term applied to basalt because they often present a stair-like aspect on weathering (C.f. The Deccan Trap).

Ultra-basic. (8) *Peridotite*—It is a coarse-grained rock of dark colour. It is a very basic type of rock consisting mostly of ferro-magnesian minerals. Constituent minerals are generally pyroxenes, olivine and hornblende. Accessory minerals include ilmenite, garnet, chromite, sphene etc.

Structures Associated with Igneous Rocks :

(1) *Dike* or *Dyke*—The word dike is of Scotch origin meaning a wall of stone. These are wall-like masses of igneous rocks cutting across a country rock which may be either

igneous, sedimentary or metamorphic. They are formed by the consolidation of magmatic material which has penetrated through fissures in the rocks. Their structure is clearly seen when they occur in sedimentary rocks because in that case they are seen to cut across the bedding planes of the sedimentary rock. Sometimes dikes are vertical. Generally they are less than 10 ft. thick. Their breadth is moderate whereas their length is great, sometimes extending over 100 miles. They are generally of hard material and erosion often removes surrounding parts of the country rocks leaving them in upstanding wall-like positions. Sometimes (but rarely) they are also eroded at a faster rate and form ditches. Commonly they produce baking effect on the two sides in the country rock and together with the indurated sides they form wall-like barriers. Dikes are abundant in regions of tension. Sometimes dikes develop perpendicular cracks and joints due to contraction following cooling. Dikes sometimes occur in swarms of parallel disposition, sometimes radially, in ring-like forms and sometimes in inclined forms enclosing cone-like masses (PL—1).

(2) *Veins*—These are more or less irregular and branching masses of igneous material cutting across the country rock of igneous, sedimentary or metamorphic rocks. Veins are often metalliferous and of great economic value. They are generally off-shoots from bigger igneous masses.

(3) *Stringers*—They are smaller and finer veins.

(4) *Apophyses*—They are tongue-like masses given out by greater igneous masses.

(5) *Sills*—These are sheet-like masses of igneous material which have penetrated into the country rock, and have spread parallel to the bedding planes as if forming additional layers in the invaded rock body. These sills are therefore clearly seen in sedimentary rocks. They may be horizontal or inclined. Sills vary in thickness from a few inches to tens of feet. Their length and breadth depend upon their spreading capacity which is again dependent on the fluidity of their material, its temperature and the weight of the overlying rocks

to be lifted. Commonly sills present a lenticular form when traced to great distances. Sills are sometimes multiple in form, occuring one after another. Sills and dikes are inter-related bodies. Often a dike gives off a sill-like mass and a sill passes into a dike-like mass as shown in the figure.

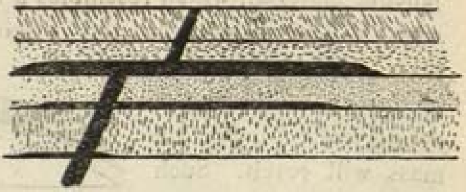


Fig.—2
Dike and Sill

Distinction between a sill and a contemporaneous lava flow

(a) Sills produce baking effects on rocks on both sides of them whereas in the case of lava flows, the baking effect is to be seen only on the lower side.

(b) Lava flows show irregular upper surfaces whereas sills have two more or less flat and parallel sides.

(c) Lava flows present spongy and scoriaceous upper sides whereas sills present hard and more or less plane upper surfaces.

(d) Lava flows often show glassy or very fine-grained rocks, whereas sills show medium-grained and often porphyritic textures.

(e) Sills often give out tongues in the overlying rock mass whereas lava flows do not.

(6) *Laccoliths* (or *Laccolites*)—These are lens-shaped structures formed by igneous rocks pushing up the overlying rocks. Laccoliths are formed by highly viscous materials which can not spread to great distances. Consequently they make their room by uplifting the overlying rocks and dome-shaped forms result in this way which are called laccoliths. Laccoliths are fed by slender necks and they have a circular flat bottom. Laccoliths are formed under-ground and come to sight only after long-continued erosion.

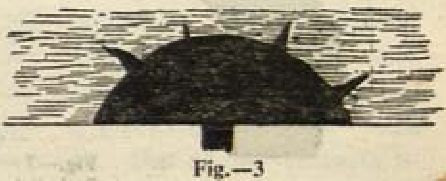


Fig.—3
Laccolith

(7) *Bysmaliths*—This is a type of structure made by igneous material, which resembles a laccolith. In the extreme case, if the magma be too viscous, then the overlying mass will be uplifted producing faults and a cylindrical p l u g-l i k e mass will result. Such forms are called bysmaliths.

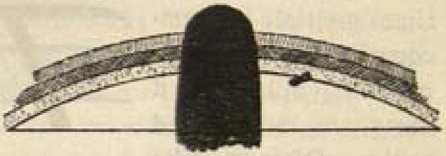


Fig.—4
Bysmalith

(8) *Lopoliths*—The word lopolith has been derived from a Greek word *lopas* meaning a basin. Such forms are exactly like tea-spoons. They have more or less flat tops and sunken bases in the form of basins.

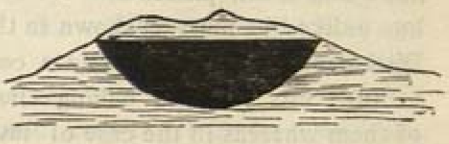


Fig.—5
Lopolith

(9) *Phacoliths*—These ar elens-shaped bodies of igneous rocks which occur in folded strata. During folding the anticlinal parts become very weak and in these regions igneous materials cellect to foım lens-shaped bodies which are called phacoliths.

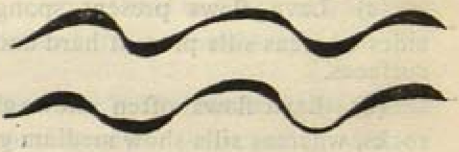


Fig.—6
Phacolith

(10) *Batholiths*—(or *Bathyliths*)—These are huge masses

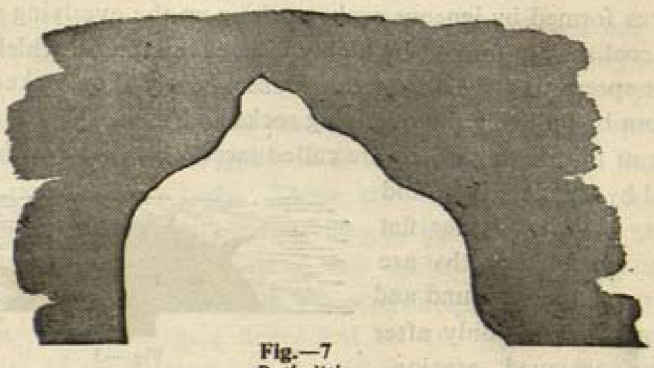


Fig.—7
Batholith

of igneous rocks formed at some depth below the earth's surface and they come to sight only after the removal of the over lying masses. They are without visible floors and have steep-sided walls. They are generally found in mountain areas as cores. The formation of a batholith is closely related to mountain-building. Batholiths make their way upwards by melting the overlying rocks or by breaking and mixing (stoping). Mountain building. processes produce some regions of weakness, if not actual empty spaces, at the core and these are later filled up by batholithic masses.

(11) *Stocks*—These are smaller masses very similar to batholiths in form.

(12) *Bosses*—These are also stock-like masses but have circular outcrops.

(13) *Chonoliths*—Other forms which do not come under the preceding regular forms are grouped under the term chonolith. They are irregular masses occuring in dislocated rocks.

So far about the plutonic and hypabyssal structures. The volcanic structures have been dealt in the chapter on volcanoes and volcanism. (Chapter—XIV).

SEDIMENTARY ROCKS

Characters of Sedimentary Rocks :

Sedimentary rocks, as the name implies, are those rocks which have been derived from the consolidation of sediments. These sediments are the products of erosion, both mechanical and chemical, from some pre-existing rock masses. The sediments are carried both in suspension as well as in solution and are deposited in basins like lakes and more commonly in seas and oceans. In case of marine deposits, remains of marine animals and plants also contribute to the accumulating mass. The consolidation of these products by pressure or by cementing materials like silica, calcium carbonate and iron oxide, produces a more or less hard rock mass. Such masses are called *sedimentary rocks.* One of the characteristics of the sedimentary rock is the conspicuous layering seen in such rock masses. Commonly this layering or stratification, as it is called, is horizontal, although it may be inclined as well. Sedimentary rocks contain fossils which are the remains of ancient animals and plants. The interlocking character of minerals, which is seen in igneous rocks, is absent here. The characteristic parallel arrangement of minerals seen in metamorphic rocks is also absent here.

The *layering* in sedimentary rocks is due to sedimentation with cessations due to a change of the velocity of the transporting agent or any change in the supply. It may also be due to the sedimentation of materials of different composition, texture and colour. Distinct layers are thereby produced. The separating plane between two layers is called a *bedding plane* and each individual layer is a *stratum*.

More Common Sedimentary Rocks :

Sandstone—This is the rock formed by the cementation of sand grains into hard mass. Silica generally constitutes the main mass. Depending upon the cementing material, the colour of sandstones at times becomes red and brown (ferruginous sandstone with iron oxide as the binding material) and white (sandstone when calcium carbonate, kaolin or silica is the binding material). When there is a considerable amount of mica in the sandstone it is called micaceous sandstone. Similarly when there is a considerable amount of felspar it is called felspathic sandstone. The individual grains of sand in sandstones are nearly round specially in the case of water and wind-borne sediments. These sand grains vary in size and several types have been recognised as—

(1) Boulder—with a size bigger than that with a diameter of 256 m.m.

(2) Cobble—with a size having a diameter between 256—64 m.m.

(3) Pebble—with a size having a diameter between 64—2 m.m.

(4) Gravel--with a size having a diameter of 2 m.m. nearly.

(5) Sand—with a size having a diameter between 2—0·02 m.m.

(6) Silt--with a size having a diameter between 0·02—0·002 m.m.

(7) Clay—with a size having a diameter less than 0·002 m.m.

The sixth and the seventh varieties will form *siltstone* and *shale* and not sandstone. In the fifth variety there are coarse, medium and fine-grained sands.

Upon the size of the constituent grains, there are several types of sandstones like fine-grained sandstone (as Raniganj sandstone), medium-grained sandstone and coarse-grained sandstone (as Barakar sandstone). The fine-grained variety points to comparatively deep water deposition than the coarse-grained variety. Very coarse-grained sandstones formed by water-worn gravels and pebbles cemented in a matrix, which may be siliceous, calcareous, clayey or ferruginous, are called *conglomerates* (PL—2). They are also called *puddingstones* because of their resemblance to pudding. There are two types of conglomerates such as—(1) Intra-formational conglomerates and (2) Autoclastic conglomerates.

(1) *Intra-formational Conglomerates*—These are formed at the time of deposition of the strata containing them. This is possible when parts of the strata are broken by earth movements or otherwise rounded by rolling and then cemented.

(2) *Autoclastic Conglomerates*—They are formed by breaking and rolling up of quartz veins or similar rocks by earth movements. The Dharwar conglomerates were thought by some to be of autoclastic origin. The distinction between intraformational and autoclastic conglomerates is that the former was formed at the time of deposition of the rocks containing them while the latter was formed later than the strata containing them.

Conglomerates serve a very important purpose in stratigraphy. Unconformities are sometimes marked by them and hence their presence indicates break in sedimentation and so they are used in marking the beginning and end of rock formations.

(a) *Arkose* is a variety of sandstone in which there is a considerable percentage of felspars, more or less resembling a granite in appearance. They weather very easily.

(b) *Grit*—It is a variety of hard sandstone in which the grains are coarse and angular.

(c) *Graywacke*—This German term denotes a variety of sandstone, usually gray in colour, which has been derived from some basic igneous rocks or argillaceous rocks. In addition to quartz grains, they contain some ferro-magnesian minerals.

(d) *Flagstone*—It is a variety of sandstone which breaks very easily into thin slabs and is used as paving and roofing material. The good cleavage is due to the presence of micaceous and argillaceous material.

(2) *Limestone*—This is a sedimentary deposit of calcium carbonate. The deposition of calcium carbonate, mostly calcite, either from solutions or from the remains of the dead bodies of marine animals, makes the formation of limestone rocks. Formation of calcareous deposits from solutions has been discussed in the chapter on underground water (Chapter-VIII). Sea animals also contribute to a large extent in the formation of limestone rocks. These animals take up calcium carbonate from sea water and build up their shells in which they live. After the death of these animals the shells sink to the sea bottom and their gradual accumulation forms limestone rocks. Sea animals like foraminifers, corals, crinoids etc. have great reputation as rock-builders. This has been discussed in the chapter on oceans (Chapter—VII). There are many varieties of limestones such as :—

(a) *Marl*—It is an impure variety of limestone containing, besides calcium carbonate, a considerable amount of clayey material. Marls of suitable composition are sometimes used as cementing materials.

(b) *Dolomite*—This is a variety which contains a good amount of magnesium carbonate. Limestones often change to dolomites. The original calcium carbonate changes to carbonates of calcium and magnesium by the percolation of magnesium salt solutions. The composition of dolomite is $CaCo_3$, $MgCO_3$.

Dolomitisation of limestone is often an important change in calcareous deposits. When the percentage of magnesium is low, the limestone is called magnesian limestone and when the percentage of magnesium is quite appreciable, the limestone is called dolomite.

(c) *Chalk*—It is a soft, loose variety of limestone in which of foraminiferal shells are abundant sometimes.

(d) *Coquina*—It is a variety of shelly limestone.

(e) *Oolite* (or *Oolitic Limestone*) — It is a variety of limestone in which the constituent parts are like small globules, just like fish roe.

(f) *Pisolite (*or *Pisolitic Limestone)*—It is a variety of limestone in which the constituent parts are bigger globular masses than those of oolite. They are like peas in pisolile.

(3) *Shale*—It is a variety of sedimentary rock which is formed by the consolidation of clay and mud. Clay is hydrated aluminium silicate in chemical composition and is formed as an alteration product of felspars in humid temperate climate. Such clays with very fine particles of mica and sand consolidate to form rock masses which are called shales and mudsstones. Shales are distinguished from mudstones by the presence of good divisional planes in them (shales) along which they break easily. When these planes are absent or inconspicuous, shales pass on to the mudstone variety.

(a) *Argillite*—This is a variety of clayey rock which is harder than mudstone and the shaly fracture is more or less absent.

(b) *Fireclay*—It is a variety of clayey rock which is commonly found in coal fields underlying the coal seams. It is so termed because it can withstand high temperature without melting. This is because, these clays, unlike ordinary clays, lack in alkali and iron materials. These materials were extracted from the soil upon which the trees, later to form coal seams, flourished in bygone days. These are used as refractory substances.

(c) *Siltstone*—It is a variety of sedimentary rocks which is formed by the consolidation of silt materials. The constituting materials have bigger grain size than those of shale and mudstone which consist of materials in the microscopic state of sub-division.

Structures Associated with Sedimentary Rocks :

(1) *Stratification*, lamination or layering which has been already referred to (PL—3).

(2) *Ripple marks*—These are wave-like surfaces produced on the sediments by the action of currents in shallow water. They may also be found on wind formed deposits. Individual wave or ripple may show a symmetrical pattern (PL—4).

(3) When soft alluvium is left exposed to air and the sun's rays for a considerable time, it dries up and shrinks. During shrinking polygonal cracks develop. They are called *mud cracks or sun cracks* (PL—5). They are most frequent where there are chances for alluvium to spread in thin layers over great areas and to get dried. Flood plains are therefore the ideal areas where mud cracks are frequently seen. Mud cracks are often preserved by being quite hardened and then quickly burried under sediments. Likewise *rain drops* and *foot prints of animals* are found preserved in ancient sedimentary rocks.

(4) *Graded bedding*—When sediments settle in suspension, the larger and heavier particles reach the bottom first and the lighter and the finer ones later. This produces an assortment of the sediments and the bedding thus produced shows larger and heavier pieces in the bottom layers and gradually finer ones in the overlying layers. Such a type of bedding is called graded bedding.

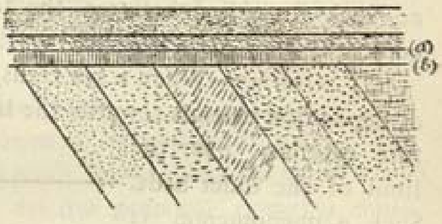
(5) *Cross-bedding* or *Current bedding* or *False-bedding*–This is another characteristic structure met in shallow water and wind formed deposits in which the layers of sediments are inclined to one another instead of following a general parallel

stratification which is so characteristic of sedimentary rocks. There is no common bedding plane and no bedding plane extends over a great length (PL—6).

(6) *Unconformity*—When groups of strata have parallel bedding planes they are called *conformable* strata and they are said to possess *conformity*. Sometimes however this parallelism is lost and one set of beds may have the bedding planes inclined to those of another set. They then lack in conformity and are said to possess *unconformity* which indicates some dissimilarity between the two sets of beds (PL—7).

There are two types of unconformity—(i) *Non-conformity* and (ii) *Disconformity*.

(i) *Non-conformity* means angular unconformity between two sets of beds. When two sets of beds are inclined to each other at an angle, they are said to possess non-conformity.

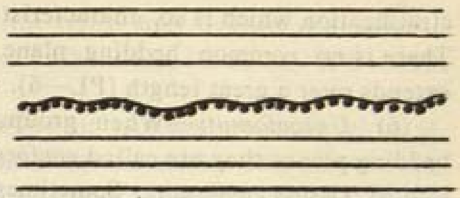


Fig—8
Non conformity

In the figure the set of beds marked (a), has a different inclination from that of the other set marked (b). These two sets are therefore said to possess non-conformity.

(ii) *Disconformity*—Suppose a set of beds, which was first deposited, has been uplifted to form land at a later period. When the beds have formed land, there will be no deposition. Suppose at a still later period the area has been depressed and gone under the sea again. Deposition will again begin and a new younger set of beds will be formed. These two sets of beds have been formed at different periods and possibly under different conditions. There exists a discordant relationship between the two sets of beds which is generally marked by an irregular surface and a bed of conglomerates at the base of the new set of beds. Such a discordant relationship between the two sets of beds is called disconformity. Disconformity is generally marked by a conglomerate bed.

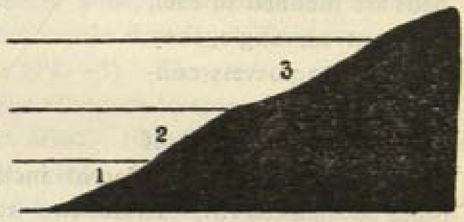
Unconformities serve important functions in stratigraphy. In grouping of strata and in the establishment of relation between rocks of different areas, the presence of unconformities is very useful.



Fig—9
Disconformity

Unconformities denote two different conditions of rock formations and altogether different geological conditions. They also denote some crustal disturbances and a period of no rock formation between the formation of unconformable beds.

(7) *Overlap*—When a sea transgresses upon land, the area of deposition extends towards the land. Each new bed, therefore extends over the limit of the older beds. Such a phenomenon is called overlap. Overlap denotes transgression by seas which may be due to either the rise of the sea level or the sinking of the land area.



Fig—10
Overlap

(8) *Offlap*—The reverse phenomenon in which the younger beds are shorter than the older beds and lag behind them is called offlap. Offlap denotes regression of seas either as a result of the lowering of sea level or sinking of sea floor or rising of the land areas.

Metamorphic Rocks

The word metamorphic or metamorphosed means changed. Metamorphic rocks generally result from the changes brought about by heat, pressure and chemical agencies, upon pre-exsisting igneous and sedimentary rocks. Those derived from igneous rocks are called *orthometamorphic* rocks and those derived from sedimentary rocks are called *parametamorphic* rocks. The work of heat, pressure and chemical solution is to produce some well defined characters upon metamorphic rocks. Metamorphic rocks are generally coarsely crystalline which distinguishes them from the sedimentary rocks. There is some parallel arrangement of minerals (foliation) which distinguishes them from the igneous rocks. They have peculiar texture. There are some minerals which are only to be seen in metamorphic rocks. The minerals are—kyanite, andalusite, sillimanite, zoisite, wollastonite, staurolite etc. There are different kinds of metamorphism produced by different agencies and there are correspondingly different products. Metamorphic rocks present some banded appearance and sometimes well developed cleavages.

More Important Metamorphic Rocks

(1) *Gneiss*—This is a common metamorphic rock. Gneiss is coarse-grained and generally shows a banded appearance. Quartz, felspars and mica are the generally occuring minerals. Accessory minerals include hornblende, augite, biotite etc. by which they are named (such as hornblende-gneiss, augite-gneiss etc.) Gneisses are sometimes produced by the metamorphism of granite type of rocks. They may also be derived from some sedimentary rocks. Gneisses are the most commonly occuring type in ancient rock masses (PL—8).

(2) *Marble*—It is the metamorphosed variety of limestone. The change produced is the appearance of a granular and crystalline character. Marble may be of many colours—white, gray, yellow, black etc. Generally it is white or light coloured. Sometimes marbles are dolomitic in composition. Marbles can be easily worked because of their softness and hence form very good ornamental building stones.

(3) *Quartzite*—This is the metamorphosed equivalent of sandstone and consists mostly of quartz. Quartzites are very hard. They often occur as veins cutting across other metamorphic rocks.

(4) *Slate, Phyllite and Schist—Metamorphism of Clayey Rocks—*

Gradual compaction produced by gradual increase in pressure produces considerable changes upon clayey deposits. The first effect is to produce shale or mudstone from clay which are sedimentary rocks. More pressure produces successively slate, phyllite and finally schist. In *slates* the minerals are very fine grained. Most notable is the presence of a well developed cleavage which is called the slaty cleavage. The easy plane of fissility renders it very suitable for being used as roofing material in thin slabs.

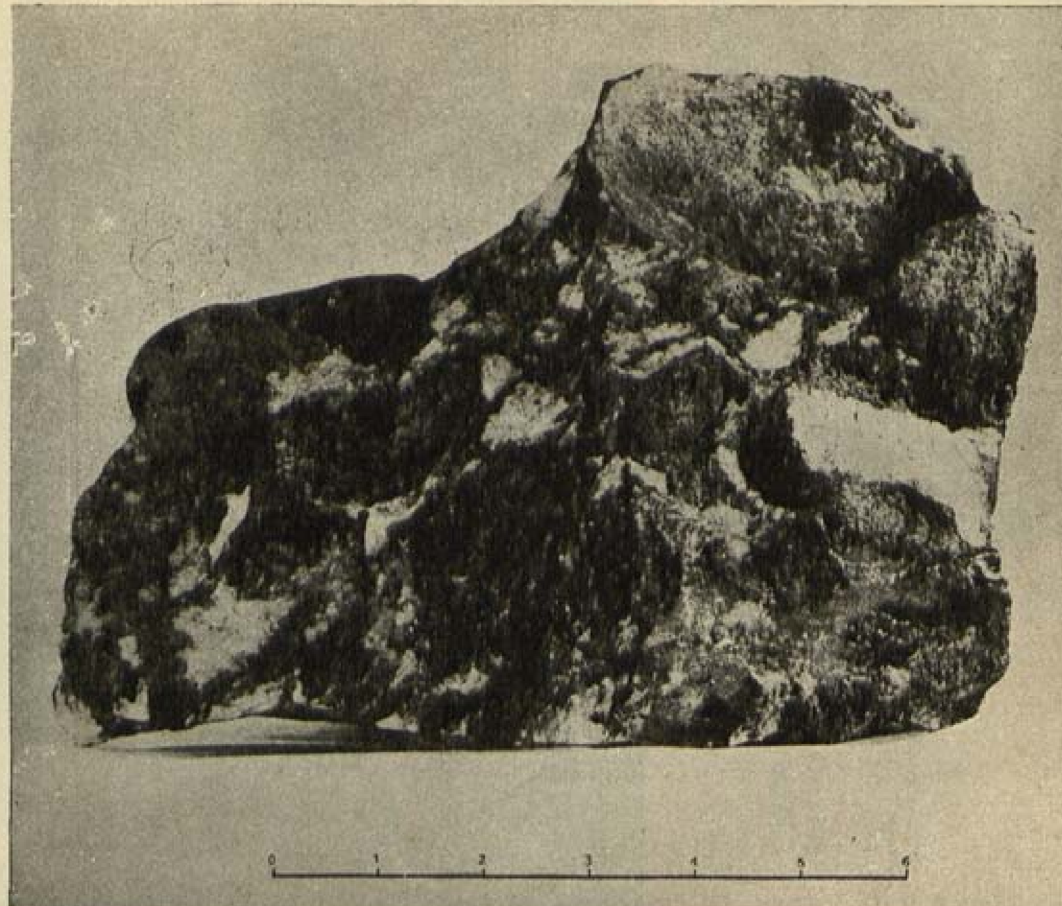
(5) *Phyllite*—These are produced with more pressure. They are more or less slate-like in appearance. The only difference is that phyllites have a glossy and shining appearance which is due to the formation of incipient mica flakes.

(6) *Schists*—Further metamorphism produces schists although they may also be derived from some basic igneous rocks. Schists possess well defined foliated or leaf-like appearance which is so characteristic that it is also called schistose structure. Micas, quartz, chlorite, kyanite, graphite, hornblende etc. are their constituent minerals. In schists also there are some minerals which mark gradual increase in the grade of metamorphism. They are (in order of increasing grade)—chlorite, biotite, garnet, staurolite, kyanite and sillimanite.

Two more rock types which are products of alteration of pre-existing rocks may be considered here. They are—

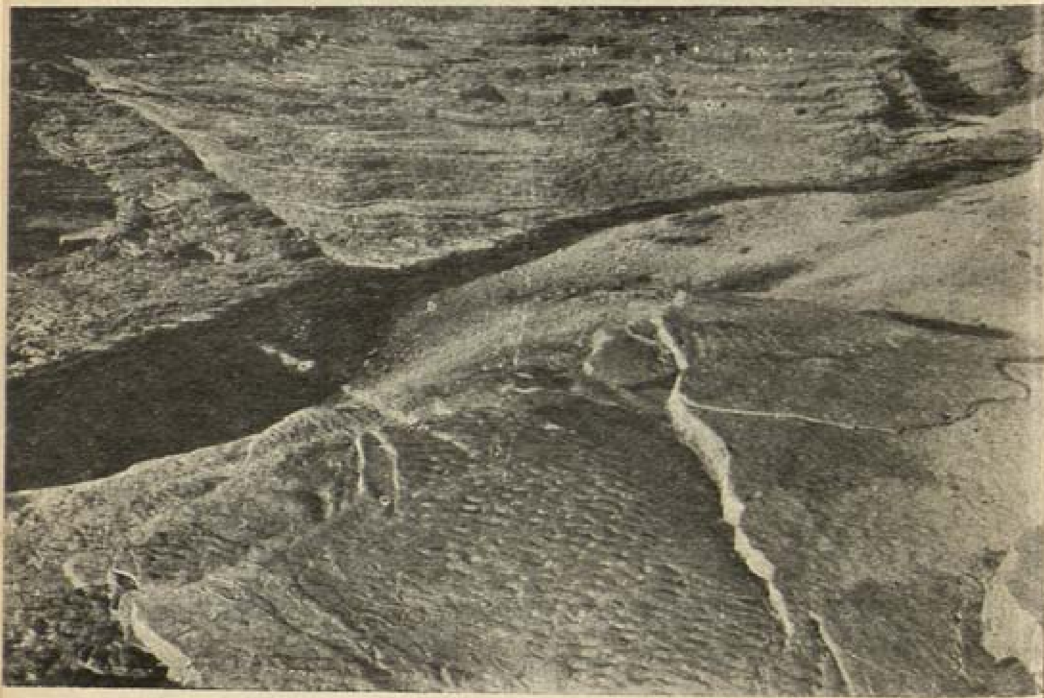
(a) *Laterite*—The word has come from the Latin word Later meaning brick because in India laterite slabs are used as building material. When freshly cut laterites are rather soft and can be cut into brick like slabs but on exposure to the atmosphere they harden. This is brownish in colour and is composed mainly of the hydroxides of iron and aluminium, and sub-ordinately of the hydrated oxide of manganese. At places the percentage of titanium oxide becomes considerable. There is very little silica, magensium, calcium and alkali materials which have been leached out from the parent rock material. There is very little of humus also. Basalts generally

Pl.—1
Ramifying dolerite dikes in Erinpura Granite
(*By courtesy, Director, G.S.I.*)



Pl.—2 Conglomerate with large rounded pebbles, Durgahati Piparia, Jabalpur
(*By courtesy, Director, G.S.I.*)

Pl.—3
Stratification in Vindhyan Limestone and Shale



Pl.—4 **Ripple marks on Glauconite** beds of the Semri series (Lower Vindhyan)
(By courtesy, Director, G.S.I.)

Pl.—5
Mudcracks

but granites and gneisses also give rise to laterite under peculiar tropical monsoonic climate with seasonal rainfall and alternating drought. There are two types of it—(i) *high level laterite* and (ii) *low level laterite*. The former type is formed at an altitude greater than 2000 ft. and is found in Bihar, Orissa, M. P. and Assam. The later type is formed at lower altitudes, even in some coastal areas, and is found in West Bengal and Madras.

(b) *Regur or Black Cotton Soil*—This has resulted from the decomposition of the Deccan basalts and occurs widely in Bombay. It contains a high percentage of the oxides of calcium, magnesium, iron and alkalies and is very fertile. It becomes very hard after it is moistened with water and then develops cracks on drying. It is extensively cultivated for cotton growing.

CHAPTER V

WEATHERING OF ROCKS

Ever since the consolidation of the earth's crust and the formation of water upon the earth, after it has sufficiently cooled, the rocks have been subjected to the wearing effects of geological agents like the running water, wind, sea waves, glaciers etc. The rocks have been attacked and bit by bit they have been made smaller and smaller. The worn down particles are then taken away from the place of their formation to be deposited elsewhere and their gradual consolidation makes the sedimentary rocks. Quite distinct sets of processes operate in the wearing of the rocks which will be discussed in this chapter.

Weathering involves the process of breaking of rocks to smaller particles and decomposition of the rocks. When the products of weathering are removed from the place of formation, the process is called *erosion.* The distinction between weathering and erosion lies in the fact that in erosion there is the transport of the products to other distant places whereas in weathering there is practically no such transport excepting for short distances by gravity. According to the transporting agent, erosion may be *fluvial erosion* (by river water), *glacial erosion* (by glaciers), *wind erosion* (by wind) and *marine erosion* (by sea water).

Weathering involves two distinct processes—one mechanical breaking or *disintegration* and the other chemical *decomposition.*

Factors influencing Weathering :

(a) Physical Factors—

(1) *Frost-action* or *frost-wedging*—This depends upon the well known property of water at its freezing point. When water freezes it expands by nearly one-tenth of its volume. Therefore when water, which has percolated into the cracks of rocks, freezes with the fall of temperature, the increase in volume

will exert tremendous pressure upon the walls of the rocks. The ultimate result will be that the rocks will be broken to pieces. This sort of disintegrating action is called frost-action. Frost-action is very conspicuous in regions of high altitudes and high latitudes. At day time water will percolate down the cracks of the rocks and at night when the temperature will fall, frost-action will take place. The presence of joints and cracks in the rocks helps the frost action to a considerable exent by allowing water to penetrate inside the rocks.

Frost-heaving is another similar effect which is caused by the expansion of water when it freezes. In inclined surfaces rock particles will be upheaved by the expansion of water below by freezing. The upheaved particles will then be acted upon by gravity and will be displaced.

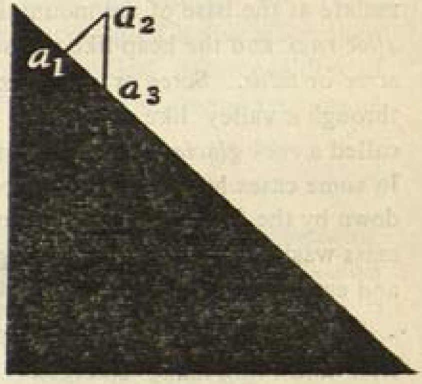


Fig.—11
Frost-heaving

(2) *Temperature changes*—With one or two exceptions like ice and some alloys, heat expands every solid. In desert regions rocks are highly heated by the scorching rays of the sun. The outer layer therefore expands considerably and gets detached from the main mass. Then again all the minerals do not expand to the same extent by heating. This differential expansion of minerals also produces distintegration of rocks.

Exfoliation is a process in which thin shells of rocks are detached from the main mass layer by layer and this produces a more or less round mass. Such a sort of weathering is called *spheroidal weathering* and the main rounded mass thus produced is called a *residual boulder*. Granites and basalts are specially susceptible to this sort of spheroidal weathering (PL—10). The attack at first starts from the corners and gradually they are worn down and this produces a round mass after which thin concentric layers are weathered off. Apart from temperature changes, chemical changes specially hydration of minerals also help in exfoliation.

(3) *Action of gravity*—This helps in weathering by exposing fresh surfaces of rocks by the removal of the weathered upper surfaces by slow downward movements of the loosened particles. In steep mountainous regions loosened weathered particles will fall down by the attraction of gravity and accumulate at the base of the mountain. The fragments are called *slide rock* and the heap-like masses formed by them are called *scree* or *talus*. Scree or talus may at favourable places flow through a valley like a stream. Such a moving rock mass is called a *rock glacier* because of its resemblance to a glacier. In some cases huge quantity of rock material sometimes slides down by the forces of gravity and other causes, and cause mass-wasting. Such sliding of huge quantity of rock fragments and earthy material is called *rock slide* or *land slide* (PL—11).

Land slides often come suddenly and cause wide destruction and bring many changes. Rivers are often blocked to form lakes. Gohana lake in Garhwal was formed in this way when nearly 5000 million tons of crushed pyrite-bearing shale and dolomitic limestone having an inclination of 45° slipped through a distance of 3000 ft. after a heavy shower of rain filling the valley of the Birahi Ganga, 2 miles wide and 850 ft. deep. Land sildes are occasional, but loosened masses of rocks in mountain masses generally have a tendency to move slowly downward. Such a slow movement is called *creep*. Creep is greatly facilitated by the lubricating action of water. *Solifluction* is a special kind of creep in which a rock mass which has been moistened by water to a considerable depth slides downward.

(4) *Water*—Weathering action of running water is of great magnitude. Water causes weathering chemically by solution and mechnically by breaking the rock mass by its dashing action.

Wind—It has been separately treated in the chapter on wind action (Chapter—IX)

(b) Biological Factors—

(6) *Animals and Plants*—Animals often produce heaps of earth which are easily removed away. Trees and plants by striking roots into the ground loosen the particles and widen the cracks. Subsequently rain-fall and wind easily remove them away. Moreover both animals and plants produce some toxic products which help in chemical solution of rocks. Plants produce an organic product called *humus* after their decay which is very helpful in chemical decomposition of rocks. Becteria is of great importance in the decomposition of rocks.

(c) Chemical Factors—

(7) *Water*—It has got both disintegrating and decomposing power. Water is ordinarily a good solvent. It can dissolve many mineral substances. *Leaching* is the term which is used for the removal of soluble substances in solution by percolating water. Chemical combination with water is called *hydration*. Hydration is often accompanied by slight increase in volume. This exerts additional pressure and acts like wedge similar to a certain extent to the frost action.

Iron minerals are easily attacked with water and the result is the formation of iron-hydroxide, limonite, $2Fe_2O_3, 3H_2O$. Limestone is not attacked by pure water but if the water contains CO_2 in solution then it becomes a good solvent of limestone. $CaCO_3 + H_2O + CO_2 = Ca(HCO_3)_2$. Its effect in limestone region has been separately dealt in the chapter on underground water (Chapter-VIII). Quartz is a fairly resisting mineral but it is soluble in alkaline water. Muscovite resists the decomposing attack by water to a great extent. Felspars are easily attacked and clay minerals are formed by the decomposition of it.

$K_2O, Al_2O_3, 6SiO_2 + H_2O + CO_2$
(Orthoclase)

$$=K_2CO_3+Al_2O_3,2SiO_2,\ 2H_2O+K_2CO_3+4SiO_2$$
(Kaolin) (Sand).

K_2CO_3 is removed in solution. Water brings about another important change, *hydrolysis,* which has also considerable effect in rock weathering.

(8) *Carbon dioxide*—Chemical combination with carbon dioxide is called *carbonation.* Its importance in the solution of limestone and production of clay from felspars has already been stated. Indirectly it supports vegetation which produces humus and thereby brings chemical weathering.

(9) *Oxygen*—Chemical combination with oxygen is called *oxidation.* Iron minerals show conspicuous colour changes by oxidation. Combination with water and oxides produces hydroxides of various elements and then they are often leached out.

The chemical agents act quite near the suface. Their effects are lessened as the depth increases. This is because dissolved substances which increase the dissolving power of the solution are removed by the interaction with other substances at quite shallow depth.

All the physical, biological and chemical agents are operating from a very remote time of the earth's history Their cumulative effect is to wear down high lands. Had there been no other forces operating in the opposite direction, all mounttains and other high areas on the earth's surface would have been reduced to flat low lands. Commonly the physical, biological and chemical factors help each other. So also the disintegrating agents help the decomposing agents and vice versa.

Importance of the Atmosphere in the Weathering of Rocks :

All the above factors of weathering excepting the action of gravity are influenced directly or indirectly by the atmosphere. Principally it consists of a mixture of several gases like N_2, O_2, CO_2 and moisture. The moisture content is a very important factor to be considered. It brings about rain and snow which feed rivers and glaciers. The importance of rivers and glaciers as geological agents is supreme and has been dealt in later pages. Precipitated water produces both disintegrating and decomposing effects on rocks.

Atmosphere also distributes heat and therefore influences effects of temperature changes.

Precipitation and CO_2 largely determine the vegetation at a place. Animals and vegetation thrive one on the other. Indirectly therefore atmosphere influences weathering of rocks through animals and plants.

Water comes from the precipitation of the moisture and the melting of snow. Snow also comes from the atmospheric moisture. How important is the function of water in disintegrating and decomposing rock masses has already been stated.

Wind is a drift of air. Its work in weathering of rocks is also considerable.

The importance of CO_2 and O_2 in chemical weathering of rocks is quite great and has been already treated. The greater part of the atmosphere is nitrogen. It is transformed into nitric acid by means of bacteria and lightning. Nitric acid is a good dissolving agent and brings about a great deal of weathering in rocks. Nitrates are also very helpful for plant growth.

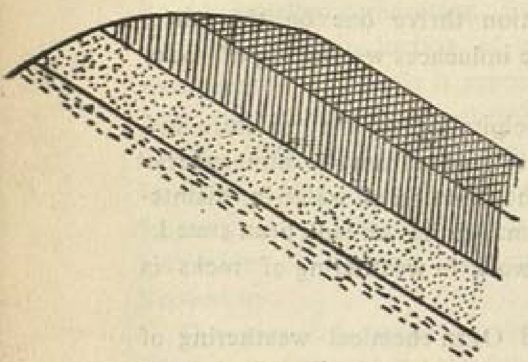
It is therefore clear how great is the importance of the atmosphere in the weathering of rocks.

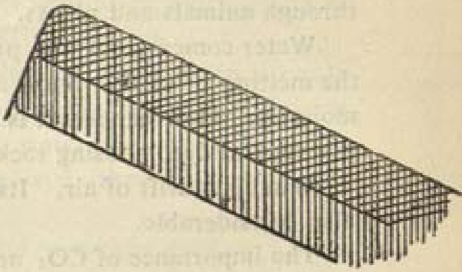
Some Erosional Features :

Badland—It is a peculiar type of land which is developed in semi-arid regions due to pronounced erosion, by running water. Such areas are very intricately traversed by gullies. This develops mostly on argillaceous rocks. In India such badlands or ravine lands are found in Agra, Mathura, Etawah etc. areas of the Jamuna and the Chambal basins, in the Siwalik regions and deforested regions of the Damodar valley.

Escarpment—In inclined beds with harder rocks overlying soft ones the more resisting hard rocks are eroded at a very slow rate whereas the underlying soft ones are eroded much more easily. The result is the formation of steep slope on one side and a gentle slope on the other. The steep side is called an escarpment. (PL—12).

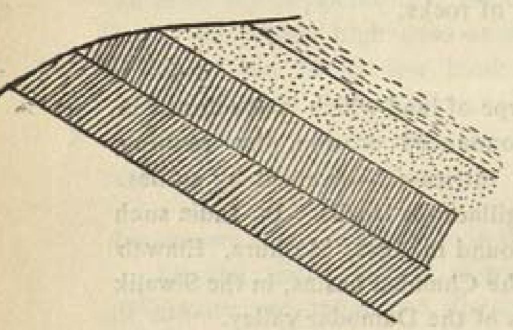
Hogbacks—These are ridge-like stuctures with high steep sides on two sides formed by harder rocks in an inclinded series of beds.

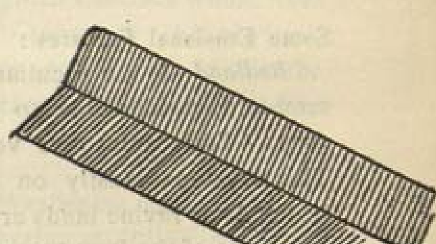




Fig—12 *Initially* *Hogback* Fig—13 *Finally*

Cuesta—It is a Spanish term used to indicate a peculiar structure produced as a result of erosion on an inclined series of alternating hard and soft beds. It has on one side an escarpment but the other side is very gently sloping.





Fig—14 *Initially* *Cuesta* Fig—15 *Finally*

Mesa—On horizontal beds with an overlying bed of hard rock, the effect of erosion is the production of a table-land

Pl.—6 Current bedding in Barakar Sandstone

(By courtesy, Director, G.S.I.)

Pl.—7 An unconformity marked by a conglomerate bed in Hornblende Schist, East of Gandemasa, Singhbhum.

(By Courtesy, Director, G.S I.)

Pl.—8 Streaky Gneiss

(By courtesy, Director (G.S.I.)

with steep slopes on surrounding sides. Such a terrace-like feature is called a mesa. The word mesa is a Spanish term meaning a table.

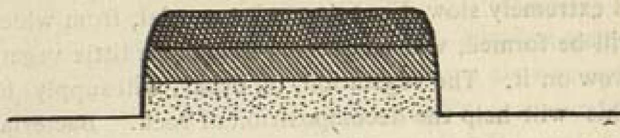


Fig. 16
Mesa

Butte—With continued erosion mesas become flat-topped hills with terrace-like aspect. Such hillocks are called buttes (PL—13).

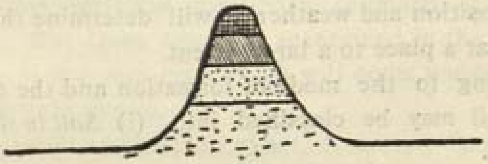


Fig 17
Butte

Soil :—

Bed rock—It is the hard rock mass underlying the loose rock materials and the soil.

Mantle—The mass of loose rock materials that covers the bed rock of an area is called the mantle or regolith. Mantle may be of two kinds—*residual mantle* which has been formed at the same place, and the other *transported mantle* that has been formed from rock particles carried from other places.

Soil—If in an area we go on digging we shall first of all get a region of very loose materials which supports the vegetation. This part is called the *top-soil*. Below this zone we will be getting more and more angular rock fragments. This zone is lighter compared to the above zone and is less weathered. This zone is called the *sub-soil*. Below this zone we will get the hard bed rock. The soil may be or may not be derived from the underlying bed rocks. If it is not formed at the same place, the soil is called *sedentary soil.* If it is formed from transported rock debris it is called *transported soil.*

Development of a mature soil which can support vegetation is extremely slow. First the rock material, from which the soil will be formed, will be decomposed and a little vegetation will grow on it. The vegetation, on decay, will supply humus and this will help the decomposition of rock. Bacteria will also help. As the process will go on, ultimately a thin deposit of soil will be formed, upon which will thrive more vegetation. Gradual decomposition of the rock and leaching of soluble material will increase the breadth of the soil zone. Abundance of rain water greatly helps the formation of soil by decomposing the rock as well as by supporting vegetation. Climate, rock composition and weathering will determine the character of the soil at a place to a large extent.

According to the mode of formation and the agencies involved, soil may be classified into (i) *Soil in situ* and (ii) *Drifted soil.*

They are further subdivided in the following ways :—

(i) Soil in situ :—

(a) *Residual soil*—It is that type of soil which has been formed at the same place where it is found. It shows clear connection with the parent rock mass below. More or less the same composition is present in the soil as well as in the bed rock.

(b) *Cumulose soil*—This is an organic type of soil. It is formed mostly by the accumulation of organic matter like peat. Mineral matter is subordinate in importance. They are best formed under marshy condition, in lakes, estuaries, dried up river beds, deltaic regions and similar water-logged areas.

(ii) Drifted soil —

(c) *Colluvial soil*—These are formed of materials accumulated at the base of a steep-sided mountain by the action of gravity. The soil, thus produced, is very meagre and is stony. It supports very little of vegetation excepting some mountain plants.

(d) *Alluvial soil*—It is formed of the alluvium brought by rivers. It is a very fertile soil. The soil of the Indo-Gangetic Plain is of this nature. It shows slight stratification sometimes.

(e) *Glacial soil*—Boulder clay or till forms at times good soil. The peculiarity of glacial soil is that it shows practically no connection with the rock below in its rock composition because the materials have been transported from other places by moving glaciers. The rock fragments have been ground very fine by glacial abrasion. There is very little of decomposed material. The felspars are practically undecomposed. The individual particles, though fine, are somewhat angular instead of being rounded as in the alluvial soil.

(f) *Æolian soil*—The wind-borne sediments at times form scanty soil. The loess deposits, mentioned in the chapter on wind action, is the only type which will come under this head. Loess soil is very fertile.

(g) *Lacustrine soil*—This type of soil is formed in the lakes. The river-borne and glacier-borne sediments collect in the lake basins and form soil at a later stage when the lakes have been dried up. Such soils are generally rich in organic matter and when the area has been well drained they form good soils.

(h) *Marine soil*—This type of soil is formed from sediments deposited on the coastal region or on the continental shelf zone of the sea and later uplifted. Such soils show stratification. They are mainly sandy and coarse-grained.

(i) *Volcanic soil*—This is the type of soil which is formed from pyroclastic materials and lavas erupted during volcanic eruptions. This type of soil is very fertile and is widely cultivated inspite of the danger of sudden eruption.

According to texture, composition, porosity, permeability, moisture-retaining capacity, content of organic matter and agricultural use, soils are also divided into several types such as follows :—

(1) *Sandy soil*—This type contains abundant sandy particles. Quartz is predominant. There is very little of clay

material. It is highly porous and has a very litte water-retaining capacity. It is not very suitable for agricultural purposes because constant watering is then necessary.

(2) *Loamy soil*—This type contains sand and clay materials, more or less in equal proportion. It is very suitable for agricultural purposes.

(3) *Clayey soil*—In this type clay minerals predominate. It has a very high water-retaining capacity. Clayey soil containing much limestone is called *marly soil*.

(4) *Black soil or Chernozem*—This is a black type of clayey soil which is generally formed from the decomposition of basalts and some other basic types of rocks. They contain a high percentage of oxides of aluminium, calcium, magnesium and a rather variable percentage of humus. The colour of the Indian black soil is due to iron compounds, whereas that of the Russian chernozem is due to the humus content. The iron and humus determine the black colour of the soil. It swells up when wet and has a high water-retaining capacity. This soil is highly fertile and is very suitable for cotton plants.

(5) *Peat soil*—This type of soil contains very little of clayey matter but mostly the decomposition products of vegetable matter. It has a good water-retaining capacity. If well drained and properly manured it forms a good productive ground for such crops as onion etc.

(6) *Podsol*—It is a gray type soil in which there is very little of iron compounds and humus. It is generally sandy and not fertile.

(7) *Lateritic soil*—This is a type of brownish soil which is composed mainly of the hydroxides of iron, aluminium and subordinately of the hydrated oxide of manganese. At places the percentage of titanium oxide becomes considerable. There is very little of silica, magnesium, calcium, and the alkali materials, which have been leached out from the parent material. There is very little of humus also. Basalts generally but granites and gneisses also, give rise to lateritic soil under peculiar tropical monsoonic climate with seasonal rainfall and alternating drought. This type has got very little

agricultural value as it lacks in the salt content and humus.

Indian Soil Types :—

Indian soils specially in the Extra-Peninsular and the Indo-Gangetic Plain are quite young and have not attained the mature stage of development. They are mostly post-Pleistocene in their formation and the soil forming processes have not got sufficient time to work upon them. In the Extra-Peninsular region, the soil is very scanty. At the base of mountains or in flat river valleys there may be a very meagre deposit of soil. The soils are mostly sandy. In the foot-hill regions of the Himalayas peat and loamy soils are found. At some places in Kashmir soils derived from glacial sediments are also found.

In the Indo-Gangetic Plain soils are mostly alluvial. In the northern part soils are sandy but towards the mouth of the rivers soils are loamy and very fertile. Near the mouths of the rivers in the deltaic regions soils are peaty and rich in humus. A large part of the Punjab (I) and Rajasthan is covered under aeolian deposits and is devoid of soil. At some places in Western Rajasthan *alkaline soil* called *reh* or *kallar* is found. Concretionary deposits called *kankar* are also found in U.P. and Bihar.

In the Peninsular part soil has attained maturity to some extent. *Regur* or *black cotton soil* is a very remarkable type of soil which covers practically the whole of Bombay State. This black cotton soil has been derived from the decomposition of the Deccan basalts. It is highly fertile and has been cultivated for years together without manuring. This is because of the high percentage of the oxides of calcium, magnesium etc. The difficulty with this type of soil is that it becomes very hard after it has been moistened with water and then develops cracks on it on drying. It is then very difficult to plough such soils.

The eastern part of the Peninsular India, specially the Madras State, shows in some parts red or brown soils. The colour is due to the iron content. Unless properly manured they have little agricultural value.

Lateritic soils are found in places of West Bengal, Bihar, Orissa, M. P. and Assam. They are seen on highlands generally. There are two types of it—*high level laterite* and the other *low level laterite*. The former type is formed at an altitude greater than 2000 ft. whereas the latter is formed at lower altitude even in some coastal areas of Madras State.

Sandy soils occur in the coastal regions. In the western coast there is a very narrow coastal area whereas in the eastern part a considerably wide coastal region has been developed. The mouths of some of the rivers have deltaic deposits mostly of silt with sometimes some organic matter.

Soil Erosion and Protective Measures :—

Huge quantity of valuable soil is eroded by running water and wind. The preservation of soil is a problem and this is more so in agricultural countries like India. Soil erosion is done in two ways—(i) *sheet erosion* which is done by surface washing or deflation by wind, and (ii) *gully erosion* which is done by running water by cutting channels.

The main cause of soil erosion is the destruction of forests that cover the land. Over-grazing by pasturing animals also destroys the protective cover of vegetation. This produces bare dry lands and they fall easy victims to mass-wasting by running water and wind. Vegetation retains moisture in the ground and this moisture acts as binding substance in the rock particles. Destruction of the vegetation therefore removes the protective layer from the land. As a consequence the land is easily eroded away. The speed of soil erosion varies from place to place with the nature of the soil, amount of rain-fall and covering vegetation.

Conservation of soil is therefore a crying need. It can be achieved by preserving the forests, controlling grazing, by proper planting of crops, by terracing and levelling the ground so as to retard the speed of running water and by storing sufficient water in the soil so as to check deflation by wind. The idea of all these processes is to preserve the valuable top soil.

CHAPTER VI

RIVERS

Before beginning with the subject proper, the following terms should be learnt, as these will be frequently used in later pages of this chapter.

Canyon and gorge—These two term denote steep-walled deep narrow river valleys. As for example the Grand Canyon of the Colorado in Arizona which has a length of 200 miles, breadth of 10 miles and depth of more than 5000 ft. in places (average depth 3400 ft.) and which has been excavated out of a plateau mass of nearly horizontal sedimentary beds of Paleozoic age underlain by some Pre-Cambrian and Archaean rocks. The Indus Gorge near Gilgit has a depth of 17000 ft.

Gradient—It indicates the inclination of the surface or the surface slope of an area. It is expressed as 1 in 100 etc.

Run off—It is the part of the precipitation which flows through rivers. It is of two types—on *surface* or *immediate run off* indicating the part which flows over the land surface and another *ground water* or *delayed run off* which comes to the surface again after percolating underground. It has been estimated that nearly 9000 cubic miles of water flow to the sea as run off in a year.

Load—It means the amount of rock material carried by a river either in solution or in suspension.

Base level of erosion—It is the mean sea level produced inland and marks the ultimate limit of down-cutting by a river. It is also called *O-level.*

Flood Plain—It is the area on both sides of a river which has been formed by flood-time river deposits and over which the river spreads in times of flood.

Development of a River System—Every tract of land on the surface of the earth is marked by irregularities. As a result when rain falls or glacier melts or spring water sprouts or a

Pl.—9
Spheroidal weathering of basalt, Bombay State.

Pl.—10
Weathering of granites. Lunavada
(By courtesy, Director, G.S.I.)

Pl.—11

Landslide in Quartzites, north of Dhasan Bazar, Nepal

(By courtesy, Director, G.S.I)

Pl.—12

Kaimur scarp, Son valley

(By courtesy, Director, G.S.I.)

lake overflows upon such areas, the water flows outward and downward taking the shortest route. Thus little gutters are formed. Such gutters are miniature streams and perform the same type of action though on a small scale. The gutters thus formed will converge at a later period downward and their union forms streamlets. Several such streamlets unite at still downward regions and form streams In this way a complex branching type of drainage system will be developed upon the area. Rivers are bigger bodies formed by the union of several steams.

Several distinct stages can be seen in the development of a river. They are the initial, the youth, the mature and the old stages.

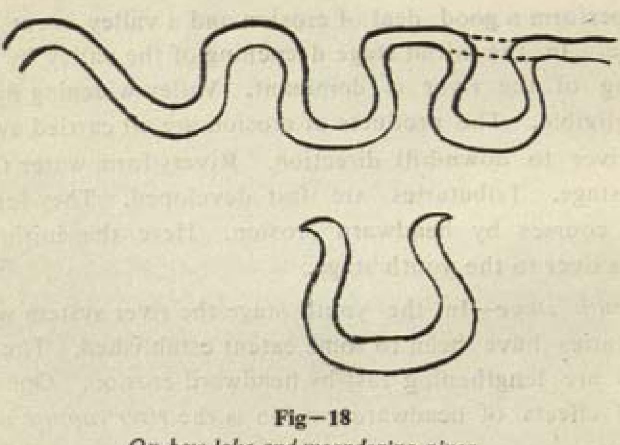
Initial stage—Rivers generally originate from mountainous regions where gradient and supply of water, either in the form of rain-water or in the form of melt water, is considerable. In the initial stage of a river, several gutters will combine to form a stream. Streams will unite to form a river. The gradient is here quite high, as a result of which the rivers can perform a good deal of erosion and a valley is cut in due course. In the initial stage deepening of the valley by down-cutting of the river is dominant. Valley widening by river is negligible. The products of erosion are all carried away by the river to down-hill direction. Rivers form water falls at this stage. Tributaries are fast developed. They lengthen their courses by headward erosion. Here the initial stage passes over to the youth stage.

Youth stage—In the youth stage the river system with its tributaries have been to some extent established. The tributaries are lengthening fast by headward erosion. One of the noted effects of headward erosion is the *river capture* or *river piracy*.

Suppose two rivers were initially flowing more of less at some inclination to each other. One river was lengthening its valley by headward erosion. Ultimately it will reach the other river and if the first river has got a greater gradient then the course of the second river will be diverted and the water of it will now be drained through the channel of the first river. This phenomenon is known as river capture or river piracy. The point where the course of the second river is diverted is known as the *elbow of capture*. The captured river is called the *misfit* and the abandoned part of the channel through which no water flows is called the *wind gap*.

Indian examples of river capture are furnished by the Arun (a tributary to the river Koshi) and by the Bhagirathi of the Ganges.

Mature stage—In this stage valley widening has begun by lateral cutting and a complex branching system of rivers will be developed. The river has now come to the plain or is flowing over a more or less flat country. The drop in gradient decreases the velocity of the river as a consequence of which the erosive and the transporting powers are also diminished. Most of the load of sediments is deposited at the



Fig—18
Ox-bow lake and meandering river.

foot-hill regions producing *fans* or *alluvial cones*. Rocks formed from fan deposits are called *fanglomerates*.

From this time the river flows with a diminished velocity. Slight irregularities in its path deflect the course of the steam. The river moves in a zigzag way. The rivers are then said to be *meandering*.

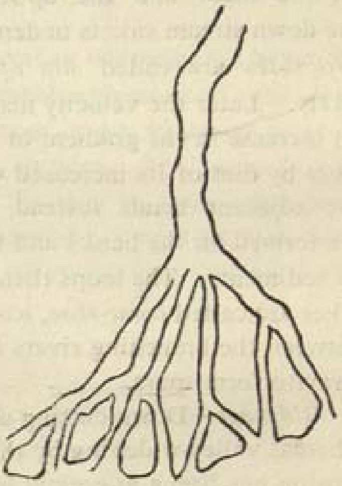
When the velocity of the river is checked very much and the river is flowing with a more sluggish rate, the loops of the meanders become more pronounced. At the inner and up-stream side of the bends the velocity of the river is slow, whereas at the outer and down-stream side the velocity is comperatively great. The result is that a thin deposit of river-borne sediments with an outward sloping side is formed on the inner and the up-stream side, wheras the outer and the down-stream side is undercut by the river current. These two sides are called *silp off slope and under cut side* respectively. Later the velocity may again be increased by either an increase in the gradient or an increase in the flow. The river by dint of its increased velocity takes a short cut across the adjacent bends instead of flowing through it. Deposits are formed on the banks and the mouth of the bend is blocked by sediments. The loops then turn to be so many lakes. These lakes are called *horse-shoe*, *ox-bow* or *cut-off* lakes. The divides between the branching rivers have now been greatly eroded away to form spurs.

Old stage—Down-cutting of the river is now diminished whereas valley-widening by the processes of weathering and erosion has begun at greatly increased rate. Down-cutting has already reduced the gradient considerably and stops at the base level of erosion which is the mean sea level produced in-land. Erosion by river is confined to the lateral cutting as a result of which the river is widened more and more. At last during the late stage of development the river valley becomes nearly flat.

In the old stage the river valley has become practically flat The river is then flowing very slowly. Frequently the river is over-flooded and builds up flood plains on both sides. The flood plains are marked by ridges formed by flood-time deposits which are called *natural levees*.

The initial irregular surface has become practically flat at the old stage of river development. This plain land produced by the river action is called *peneplain*. Though nearly smooth, here and there some mounds or small hillocks of hard rocks still persist. These hillocks are called *monadnocks* (after the name of Mt. Monadnock formed in this way in New Hampshire in U.S.A.).

At the last stage the river falls to the sea or to a lake. Rarely it may terminat e in a marshy land or in a desert. When it meets the sea or a lake, a river may form a *delta*. Deltas are triangular structure built by river deposits. The name is because they resemble the Greek lettter △ (delta). In a deltaic deposit three distinct layers are seen. The ground layer is formed of finer sediments and is called *bottom set* bed. After this is the middle layer consisting of coarser material. This layer is called *fore set bed.* The upper layer is formed of a mixture of coarse and fine material and is called *top set bed.*



Fig—19
Delta

The formation of a delta starts at the mouth of a river. where the river meets with calm expanse of a sea or a lake The ideal condition for the growth of a delta is that the sea or the lake must be tideless and the velocity of the river will also be sluggish and there will be a sufficient load of sediments in the river. Under these conditions (all of which are seldom present) the load of sediments is deposited at the mouth of the river and gradually the deposits come over water to form a delta. Deltaic structure obstructs the flow of the river and the river divides itself into so many branches to fall to the sea. The branches are called *distributaries.* The part of Southern Bengal to the east of the Hooghly River up to the River Padma is the famous delta of the Ganges.

Such a developmental course is followed by each river. Later with the uplift of the source region, the gradient may again be increased. The river will then begin down-cutting and valley deepening and the whole course will be repeated. Such a cycle of processes from the initial or mountain stage to the old or delatic stage is called a *fluvial cycle*. Such cycles recur one after another. Commonly one cycle is not fully completed because of disturbing earth movements.

Development of a River Valley :—

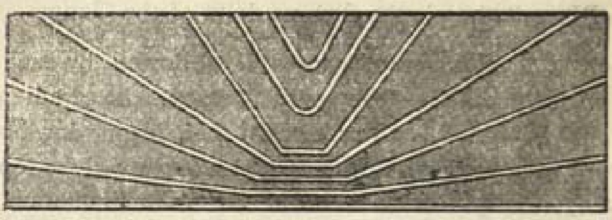
Each river occupies a valley which it has excavated, though sometimes rivers occupy valleys which are pre-exiting. The later type of valley is modified by the river action.

Development of a river valley depends upon several factors such as climate, composition of the bed rock and the surface relief.

Initially the concentration of rain water or melt water in to the shortest routes down-hill causes the formation of little valleys which are occupied by rivulets. It may also be initiated by the presence of several pot-holes more or less in a linear tract or by the retreat of a water-fall. More and more run off through these little valleys enlarges them. They widen a little but are deepened much more as in the earlier stages of development the down-cutting by rivers preponderates over lateral-cutting.

The valleys in the young stages are lengthened headward by head erosion. Perchance some other rivers may be captured in this process of head erosion. This will add to increase the discharge as a result of which more and more erosion, mostly in the form of down-cutting, will ensue. Down-cutting produces deep gorges but there is a limit to the process of down-cutting. Commonly it stops when the base level of erosion is reached at a late stage.

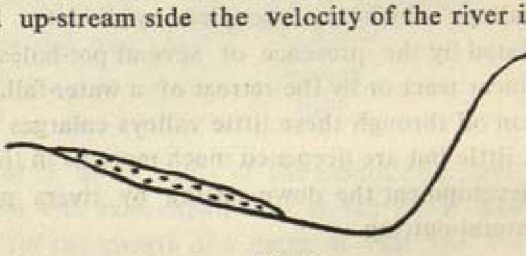
The young valley has a V shaped cross-section. The V



Fig—20
Valley widening

widens out as the valley reaches maturity more and more. Lateral cutting by the river erodes the valley sides at a faster rate than that by valley-deepening. This brings more and more flatness to the valley floor.

The gradient has decreased considerably by this time. Considerable amount of sediments has been formed and the river has to use nearly all its energy in transporting the load. This reduces the velocity of the river. The course of the sluggish river is thrown to the sides by the irregularities on the valley floor. The river is now meandering on the valley. In the first stage the valley of a meandering river is narrow. At the inner and up-stream side the velocity of the river is slow. The water dashes directly on the outer and the down-stream side causing it to be eroded



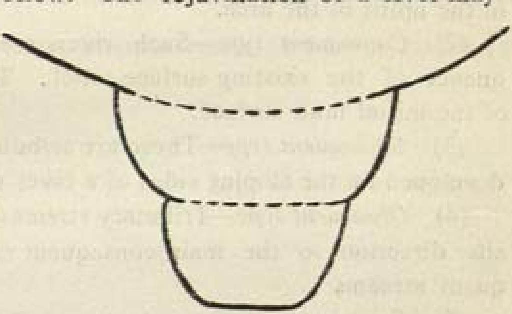
Fig—21
Slip off slope and under cut side

quickly. The water here is the deepest and side is also steeper compared to the inner and up-stream side. This causes the deposition of sediments on the inner and up-stream side and considerable erosion on the other side. The result is the formation of *slip off slope* on the inner side and an *under cut side* on the outer.

Gradually the projections of the curves on the valley are eroded away and the valley floor is widened. This produces finally a continuous valley with a more or less flat floor containing the meandering river. The width of the valley is much greater than the width of the river here. Such a valley floor is called *strath*.

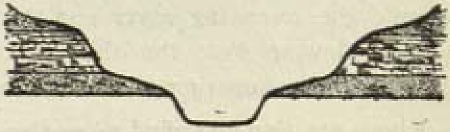
In the later stages of development the valley continues to widen but with a slower rate. Down-cutting has practically stopped. The valley has become nearly a plain with very gently sloping sides. The development is now complete. The valley has become old.

Later uplift in the source region causing increase in the gradient may increase the velocity of the river. Down-cutting then again begins and more or less the same cycle, as mentioned above, will follow. The rejuvination of a river may arrest the valley development at any stage and the earlier stages will begin with it. This produces a step-like aspect in the river valley and the number of such cycles of development processes can be inferred from these steps. (PL-14)



Fig—22
River valley showing rejuvinations

These step-like features are however to be differentiated by field observation from the river or rock terraces that are produced by differential erosion of soft and hard rocks composing the bed rock of a river valley.



River terraces
Fig—23

The rejuvination of a river in the meandering stage produces more deepening of the valley with the still maintenance of the winding course. Such gorges are called *incised meanders*. The bends of the incised meanders are seperated by wall-like projections which are eroded away at a later stage.

Types of Rivers—From the point of development and origin several distinct types of rivers can be recognised. They are :—

(1) *Antecedent type*—Such rivers were existing before the surface relief was impressed upon the area as for example, the Indus, the Sutlej and the Brahmaputra. These Himalayan rivers have cut transverse gorges across the mountains. The uplift of the Himalayas increased their gradients and their increased erosive action was able to maintain their course across the mountains. Such rivers are able to maintain their original course inspite of later crustal deformation resulting in the uplift of the area.

(2) *Consequent type*—Such rivers are formed as a consequence of the existing surface relief. They follow the slope of the initial land surface.

(3) *Subsequent type*—These are tributary rivers which are developed on the sloping sides of a river valley.

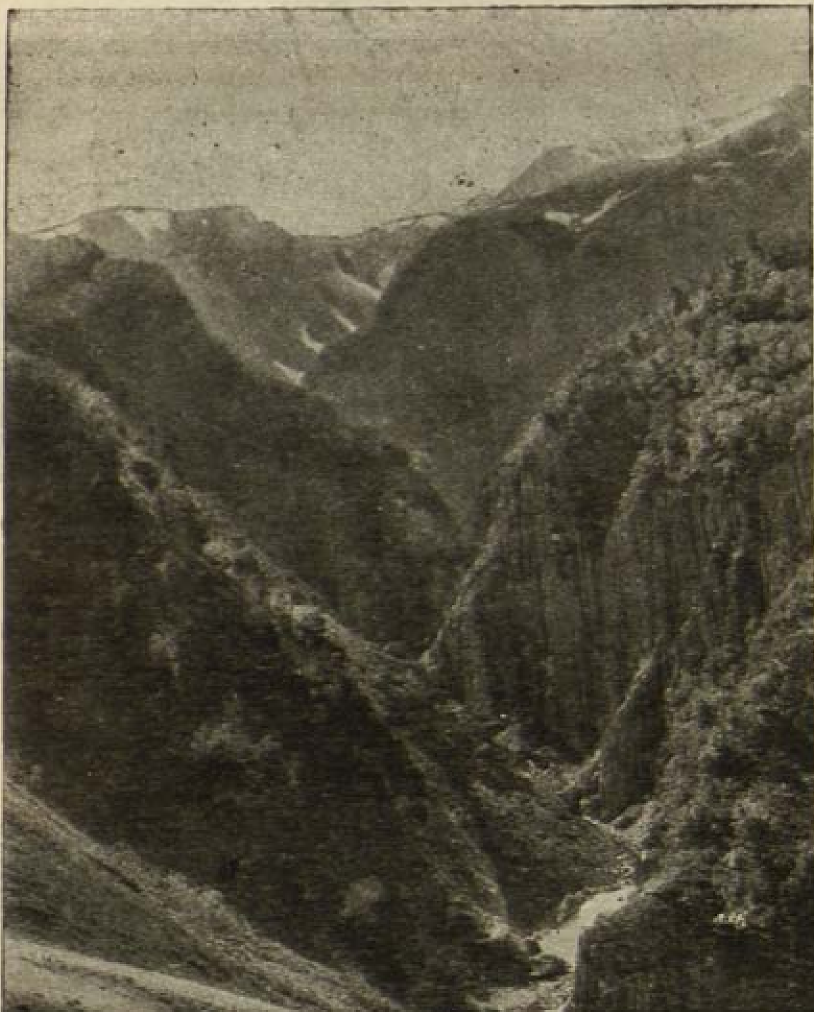
(4) *Obsequent type*—Tributary streams flowing in an opposite direction to the main consequent rivers are called obsequent streams.

(5) *Superimposed type*—At some places old rocks may be covered under a sheet of new deposits. Any river that will be developed on such an area will follow the surface relief of the overlying cover and will not have any relation with the older rocks lying below. Gradual erosion by the river will remove the overlying cover and the river with its tributaries will be flowing over the older rocks below. The rivers are then said to be superimposed on the older rocks below.

Rivers are also classified as *marine* or *continental* depending on whether they do or they do not enter the sea, and as *longitudinal* or *transverse* depending on their courses being parallel or transverse to the direction of the folding of a mountain or any such long structure.

Pl.—13 Butte of Rewa Shales, Bhainsrorgarh. *(By courtesy, Director, G.S.I.)*

Pl.—14 Three river terraces as seen in Bunji oasis. *(By courtesy, Director, G.S I.)*



Pl.—15

Gorge of the Zozila (*By courtesy, Director, G.S.I.*)

Geological Action of Rivers and the Associated Forms :—

River erosion :—

Erosion by river is done principally in four ways. These are—(1) *Hydraulic action*, (2) *Corrasion*, (3) *Attrition* and (4) *Corrosion*.

(1) *Hydraulic action*—Forces inherent in the flow of running water can perform a good deal of mechanical erosion. It can loosen fragments of the rock from the river bed and the sides, and remove them along with other loose materials. This process is clearly illustrated by a heavy shower of rain in a ploughed field.

(2) *Corrasion or abrasion*—It means the mechanical abrasion of the rocks of the river bed and the sides. The current of the river carries a considerable quantity of rock waste as the load. Fragments of the rocks are always striking against the bed and the sides of the river valley. The result is that rocks are getting eroded and the products of abrasion are carried by the river current. Fresh exposures are thereby made and the rocks are more and more eroded away in this way. The rock wastes serve as the tools of destruction for the river current.

The formation of *pot-holes* is one of the illustrations of this process. These are more or less rounded or ellipsoidal hollows in the form of vertical shafts. These are made on the river beds by the mechanical abrasion done by revolving rock fragments caught up in whirling eddies of river currents. When the revolving rock fragments are worn down, near ones take their place and the deepening of the pot-hole goes on so long as the river has got sufficient current strength.

(3) *Attrition*—It is the mechanical wear done on the transported rock fragments themselves. During corrasion and transit, these fragments often collide among themselves, the bed rock and sides. As a result they are worn down. Bigger boulders are worn down gradually and cobbles or pebbles are worn down to sands or silts.

(4) *Corrosion or solution*—It means the chemical erosion by river water. The dissolving power of the river water is increased by the presence of some aiding substances like alkali

matter and some gases like carbon dioxide etc. The solubility of the materials composing the bed rocks also determines the part of the corrosion by river water.

Factors influencing River Erosion :—

(1) *Surface relief*—This determines the gradient upon which the velocity and the erosive power of a river depend.

(2) *Climate*—It determines the precipitation and finally the volume and the velocity of the river. Upon the velocity depends the erosive power of a river. It has been estimated that velocity varies as the square of the abrasive power i.e. if the velocity be doubled, the erosive power will increase four times.

(3) *Nature of the bed rock*—If the rocks be soft, erosion will be maximum. River water meets with little difficulty in loosening fragments of such rocks whereas if the rock be hard it will be difficult to erode it and consequently river erosion will be checked to a very great extent. The solubility of the materials composing the bed rock also determines the rate of river erosion. If the bed rock be composed of materials which are easily soluble, then the river can perform a good deal of erosion when flowing over such a land. On the other hand if the bed rock be composed of materials which are difficultly soluble, then the river erosion will be minimum, other factors remaining equal. In the case of sedimentary and metamorphic rocks, the layering is also an important factor. Horizontally layered rocks are more easily eroded away than the vertical ones. In the case of inclined beds, if the inclination be in the same direction as the river flow, then erosion will be greater than when the inclination of the beds is in the opposite direction to the river flow.

(4) *Presence of joints and fissures in the bed rock*—Presence of good many fissures and joints in the bed rock facilitates erosion because water can then penetrate to a great depth and consequently a greater area will be exposed to both the mechanical and chemical erosion by the river water.

(5) *Hardness of the transported materials*—As already pointed out the fragments in transit serve as tools of destruction in the case of river erosion. If these fragments be of hard material, mechanical erosion will be maximum. It is obvious because soft materials can do very little erosion as they are likely to be worn down very easily.

(6) *Dissolving power of the river water*—This necessitates the presence of some dissolved materials and gases in river water. Though ordinarily water is a good solvent, its dissolving power is more increased by the presence of some suitable materials in solution with it.

(7) *Nature of the river*—The velocity of a river in a deep narrow channel is greater than that in a broad channel of shallow depth because of greater friction from greater area in the latter case. As the erosive power of a river varies with the velocity, river erosion will be more pronounced with a deep narrow river than with a broad shallow one. The velocity is also dependent on the gradient. The volume of a river also determines to a large extent the velocity. Gradient and the form of the channel being equal, the velocity varies with the volume. It has been estimated that a river with eight times larger volume will flow with a velocity doubly swifter. This explains why a river is more destructive in times of flood. Rivers which are subject to great variations in velocity and volume can perform more erosion than those which are more or less uniform.

River Transport :—

The products of erosion are carried by the current of the river to other places. Rivers transport not only the products of their own erosion, but to the load are also added materials of other mass-wasting processes. Materials from landslides slumping, avalanches, ground water and wind-borne sediments are also largely transported by rivers. Rivers are the most important transporting agent in nature. What a large quantity of materials is transported by rivers can be thought of from the following figures of silt-carrying capacity of the

Ganges, the Brahmaputra and the Indus. The Ganges carries 90,000 tons, the Brahmaputra over 1,000,000 tons and the Indus 1,000,000 tons of silt per day.

Transport of rock materials by rivers is effected in two ways—one mechanically and the other in solution. Mechanical transport of materials by rivers is influenced by three factors—(1) velocity of the current, (2) nature of the river current and (3) density of rock materials to be transported and buoyancy due to river water.

(1) *Velocity*—Transporting power of a river varies directly as the sixth power of its velocity, that is when the velocity is doubled, the transporting power becomes 64 times increased. This holds good in the case of coarse materials only and not in the case of finer products.

(2) *Nature of the river current*—Suspended fine particles are very easily carried away by river current. The heavier ones, resting on the bottom can be to some extent pushed along with the forward moving currents. They generally require to be lifted before they can be carried forward. At favourable places the whirling currents can lift the particles but this is not the case everywhere. With slight change in position the particles can be pushed further. River channel has sloping sides. This imparts a tendency to the sediments on the sides to move to the central region by the force of gravity. Irregularities of the bed of the river create many changes in directions of the currents. Moreover the velocity is maximum at the central region because of less friction here. These factors cause, every now and then, some changes in the positions of the materials lying at the bottom. Sometimes they are lifted up even, thus facilitating easy transport.

(3) *Density of the rock materials and the buoyancy due to river water*—Every object loses apparently a part of its weight when immersed in water. Thus it is easier to move a full pitcher under water than to lift it above water. In the case of solid materials those with low sp. gr. can remain suspended easily and hence can be carried to greater distances. Heavier ones

collect at the bottom but even then they are made apparently lighter under water because of buoyancy. This lessens the burden on the current. Had there been no such property of water, the transport of the materials by rivers would have been much more difficult. The presence of salts in river water increases the density of it which in its turn produces more buoyancy thus facilitating the transporting action of rivers.

Materials carried in Solution—Apart from the mechanically carried sediments, a huge quantity of materials is carried in solution. This quantity comes from the solution of the soluble materials of the bed-rock over which the river flows together with the amount contributed by the underground and rain water. These materials include carbonates of calcium and magnesium, sulphates of calcium, magnesium, potassium and sodium and the like. The contribution of these salts to the seas by rivers is increasing the salinity of the sea water every y ear.

River Deposition :—

Where the velocity of the river is checked, deposition of the sediments takes place. Obstructions to the velocity are offered by the irregularities in the river course and more specially at the curves. It has already been seen in the case of meandering rivers that the deposition takes place at the inner and up-stream sides. Such places are favourable sites for deposition and prospectors have specially to examine such bends for placer deposits like gold, cassiterite, wolfram etc.

All the factors, which tend to diminish the velocity of rivers influence the deposition of sediments. Loss of gradient is an important factor. It has already been discussed in the case of development of rivers that the plain stage of a river is mainly marked by deposition. This is because of the fact that the gradient here is considerably less than that in the mountain stage. It has also been stated that where a river abruptly falls on the plain from a mountain, deposition at once takes place resulting in the formation of alluvial cones and fans. Such depositional features are so named because of their resemblances to cones and fans. In the case of fans the vertex is at the place where the river falls on the plain. Its thickness is maximum at this place and it widens and thins out at greater distance. The union of several such fans makes a more or less continuous plain in front of the mountain. Such plains are called *piedmont alluvial plains*. If the water is absorbed by sediments, the deposits can not spread out and in that case a more or less conical structure is formed which is called an *alluvial cone*.

Loss of volume resulting in the decrease in velocity also causes deposition. This is specially manifested after floods. During flood time a river does considerable damage by means of its sudden increase in volume but when the flood subsides, the volume of the river gets diminished and consequently there occurs a good deal of deposition in the form of alluvial deposits.

Where a river, charged with considerable sediments, meets a tideless sea or a lake, deposition of the sediments takes place and deltas are formed. More or less similar deposition makes bars across the mouths of rivers.

One of the peculiarites of the river-borne deposits is the sorting of the sediments. The heavier and the larger ones do not travel much and are deposited near the source, whereas the lighter and the finer sediments are carried to greater distances.

Graded River and Profile of Equilibrium :—

In the early stages of river development, the gradient is considerable and hence erosion in the form of valley-deepening is more pronounced. Continued down-cutting reduces the gradient and with cosequent loss of velocity, the erosive power is diminished. Then the products of earlier erosion are to be handled also. When a considerable amount of rock waste has been formed, the river has to spend most of its energy in transporting the sediments. Consequently the erosion is diminished. In the mature stage therefore a sort of equilibrium is reached between the erosion on the one hand and the deposition on the other. When there is more erosion than the normal, the gradient becomes less. This reduces the erosive power by diminishing the velocity, and the transporting power is also diminished. This results in deposition of a part of the sedimentary load that the river is carrying. The deposition again builds up the normal gradient at some other place. Thus excess of erosion is immediately compensated by excess of deposition and vice versa. Thus a state of balance is reached between the erosion on the one hand and the deposition on the other. When this is attained the river is called a graded river or is at grade and its profile is then called a profile of equilibrium or a graded profile. At the time of erosion a river is degrading and at the time of deposition the river is aggrading.

Depositional features illustrating the work of rivers include alluvial cones, fans, piedmont alluvial plains, flood plains, natural levees, deltas, bars etc. All these have been described in the previous pages of this chapter.

INDIAN RIVERS

Indian rivers can be divided into two major groups—(i) those of the Peninsula and (ii) those of Extra-Peninsula.

Peninsular Rivers :—

These rivers possess some peculiarities in the fact that majority of them have reached the old stage. They have reached the base level of erosion, and have wide and nearly flat valleys in which they meander sluggishly. In times of heavy showers of rain they become quite full and are often over-flooded causing immense damage to crop and property, thus bringing untold miseries to the people. For the most part of the year, they go on depositing their sedimentary load here and there in their courses.

Most of the Peninsular rivers follow an easternly course. Dr. H. L. Chhibber points to a radial drainage from the central Indian highlands. This is corroborated by the easternly flowing Damodar, by the south-easternly flowing Subarnarekha, by the southernly flowing tributaries of the Godavari like the Wainganga and the Wardha, by the westernly flowing Narbada and the Tapti, and the northernly flowing tributaries of the Jumna like the Chambal, the Betwa and the Ken, and the Son, a tributary to the Ganges.

Among the more southern rivers of the Peninsula an easternly drainage can be seen. With the exception of the Narbada and the Tapti and the small rivers which start from the Western Ghats and fall into the Arabian Sea, all the rivers like the Mahanadi, the Godavari, the Kistna, the North and the South Pennars, the Cauvery etc. follow an easternly course. The Western Ghats serve as their water-shed. This abnormal phenomenon is explained by two assumptions. One of them states that the Deccan Plateau received an easternly tilting at the time of the Himalayan upheaval. Another explanation is that the western half of the continental block, of which the Western Ghats are the backbone, has been faulted and gone under the Arabian Sea. The western coast of the Peninsula is a faulted region undoubtedly and hence the second explanation is more in keeping with the observations. We are therefore getting the rivers east of the Western Ghats, whereas those to the west have been submerged along with that tract containing them.

The westernly flow of the Narbada and the Tapti is explained by the assumption that these rivers are flowing along two fault lines and not in the v alleys cut by them. There are also a good many small rivers following an westernly course which arise from the Western Ghats and fall into the Arabian Sea. These are fed by rain water and become highly torrential during the monsoon periods. Hence they can not build any extensive deltaic deposits at their mouths and except in Gujrat there is a very narrow coastal strip on the west coast of the Peninsula. As a contrast to these the easternly flowing rivers like the Mahanadi, the Godavari etc. have built extensive deltaic deposits at their mouths.

The little southern rivers often make falls and cascades. They have therefore great potentialities as sources of hyhro-electric power. Some of them have already been trapped and schemes for several others are also awaiting execution.

The Extra-Peninsular or The Himalayan Rivers :—

The following peculiarities are to be noted in the case of the Extra-Peninsular rivers.

(1) *Antecedent drainage*—The Himalayan rivers like the Brahmaputra, the Sutlej and the Indus illustrate this type of drainage. These three are amongst the oldest rivers of the region and were in existence much before the main uplift of the Himalayan mountains. The gradual upheaval of the Himalayas was increasing their gradients. As a result their erosive powers were also increasing and hence they were able to maintain their courses right across the Himalayan chain. These three rivers rise in the Tibetan side beyond the high mountain peaks of the Himalayas.

(2) *Transverse gorges*—These have been cut across the Himalayan chain of mountains by some of the Extra-Peninsular rivers. They are deep chasms and run across the main mountain chains. The most prominent one is the Indus gorge near Gilgit which has a depth of 17,000 ft. Apart from their formation due to the down-cutting by rivers several other explanations have been put forward to account for their origin. It is believed by some that they have been formed by the widening of fault planes by rivers flowing through them Another idea is that they have been formed by the sudden escape of dammed up rivers. They may also be due to head erosion specially in the case of smaller rivers.

(3) *Head erosion*—Many of the rivers of the Himalayan region have cut their valleys back by headward erosion and some of them have captured other rivers flowing through different channels and in different directions. Examples of such river capture are furnished by the tributary Arun of the Kosi river, the Bhagirathi of the Ganges and others.

There are twenty three principal rivers belonging to three major river systems in the Extra-Peninsular region. They are :—

The *Brahmaputra system* consisting of the Brahmaputra, the Luhit, the Dibang, the Subansiri, the Manas, the Sankosh, the Raidak and the Teesta, the *Ganges system* consisting of the Kosi, the Bhagmati, the Rapti, the Gandak, the Karnali (the Gogra on the Plains), the Ramganga, the Khoh, the Kali (or the Sarda), the Jumna and the Ganges and the *Indus system* (mostly flowing through West Pakistan) consisting of the Sutlej (Satadru), the Beas (Vipasa), the Chenab (Chandrabhaga or Asikni), the Jhelum (Vitasta) and the Indus (Sindhu).

Most of the above rivers are fed by the melt water from the Himalayan glaciers and are perennial. Others are fed by rain water and have variable discharges. The mean annual water supply in the rivers of India is nearly 2,300,000 cu. ft. per sec. of which nearly 94 p.c. flows to the sea and the remaining is used in irrigation and agriculture.

Dr. H. L. Chhibber has classified the Extra-Peninsular rivers into four groups.

(1) The Tebetan or the Pre-Himalayan rivers like the Indus, the Sutlej and the Brahmaputra.

(2) The Great Himalayan rivers like the Ganges, the Kali the Gogra, the Gondak, the Teesta etc. They are likely to have been formed just after Middle Miocene i.e. after the second upheaval of the Himalayas.

(3) The Lesser Himalayan rivers such as the Beas, the Ravi, the Chenab, the Jhelum, etc.

(4) The Siwalik rivers such as the Hindan and the Solani near Dehra Dun. They are post-Pliocence in age.

A brief description of the main rivers like the Brahmaputra, the Ganges, the Jumna and the Indus is given here.

The Brahmaputra—In its upper course it is known as the Tsang Po. It rises near the Manasorowar and then flows through the Ladak and the Great Himalayan Ranges for nearly

1000 miles and then takes a turn towards the south at Namcha Barwa in ahe north-east of Assam. It is here known as the Dihang and when it falls on the plains it is called the Brahmaputra. In the recent past this river has changed its course. On the plains it is joined by the Teesta and itself joins the Ganges and forms the Padma to flow into the Bay of Bengal through East Pakistan. Other tributary rivers have been mentioned in the Brahmaputra system of rivers.

The Ganges—The Bhagirathi and the Alakananda are the two main tributary rivers to form the Ganges which join at Devprayag. The Bhagirathi originates from the Gongotri glacier near Kedarnath and is joined by the Jahnavi on its way. The Alakananda has been formed by the union, at Joshimath, of the Dhauli from the Zanskar Range and the Vishnuganga and is also joined by the Pindar from the Nanda Devi and the Mandakini. The Ganges after its union with the Jamuna at Prayag flows over Uttar Pradesh, Bihar and West and East Bengals. Near Murshidabad in West Bengal it is divided into two branches. One of them, the Hooghly River, flows straight to the Bay of Bengal and the other, the Ganges, joins the Brahmaputra to form the Padma and the later flows to the Bay of Bengal (through East Pakistan). The other tributary rivers have been mentioned in the Ganges system of rivers.

The Jumna—It rises from the Jumnotri glacier and is joined by the Tons and the Giri rivers. The Jumna joins the Ganges at Prayag i.e- Allahabad.

The Indus—It rises near the Mount Kailash and is fed by two rivers, the Singi Kampa and the Gartong Chu in its source region. It flows by the Ladak Range and the Nanga Parbat and takes a turn and flows to the plain. In the mountainous region its main tributaries are the Zanskar, the Dras, the Shigar, the Gilgit, the Kabul and the Khurram rivers and on the plain it is joined by the Sutlej and flows over the Punjab and Sind, and then falls to the Arabian Sea. The Sutlej is joined by the the Beas and the Chenab. The Chenab is again joined by the Jhelum and the Ravi. The Indus system of rivers mostly flows through West Pakistan.

WATER-FALLS

When a river falls from a vertical escarpment it forms a water-fall. If the steepness is not pronounced, it is called a rapid. When the water descends over a step-like structure, it is called a cascade, and if the volume of water in a water-fall or a rapid is huge, it is called a cataract.

The origin of water-falls and all the related features is due generally to differential erosion. When a hard rock lies above a soft rock, the soft rock below is eroded with greater rapidity than the hard rock above. As a result the river bed is steepened and a rapid or a water-fall originates. Water-fall may also originate as a result of glaciation, specially in hanging valleys. The damming up of a river for sometime converts the river into a lake and water at its flanks spills out in the form of water-falls below. Vertical movement of parts of the crust due to diastrophic movement or faulting can also produce water-falls. The breaking up of rocks along joint-planes may produce a water-fall, of which the Hundroo Falls in the Ranchi district, Bihar, is an example.

The highest Indian water-falls in Gersoppa of the Swaravati River in N.W. Mysore, consisting of Raja, Rocket, Roarer and Dame Blanche and having a fall of 850 ft. During the monsoon time it becomes very great in volume but during the summer it is reduced considerably. There are also many falls in the Western Ghats. The Shivasamudram Falls of the Cauvery in Madras (300 ft.), the Gokak Falls of the Gokak River in Belgaum in Mysore (180 ft.) the Yenna Falls near Mahabaleshwar in Bombay (600 ft.) the Dhurandhar Falls of the Narbada in the Jubbulpore district in M. P. etc. are noted Indian examples of water-falls. In Bihar, the Hundroo Falls, 27 miles from Ranchi (320 ft.) of which the sheer drop is 200 ft. and width nearly 20 ft., the Jonha Falls (now named

Gautamdhara) 23 miles from Ranchi and the Usri Falls near Giridih are some examples. Beadon, Bishop and Elephant Falls near Shillong in Assam may also be mentioned. Falls are also numerous in the Himalayan region.

CHAPTER VII

OCEANS

The oceans occupy nearly 71 p.c. of the surface area of the earth. They generally taper northwards. The oceans are the major bodies of water and the seas are the minor ones being parts of the oceans which are generally partially surrounded by land areas. A bay is a body of water which is more or less surrounded by land whereas a gulf intrudes further inland. Examples of these are the Indian Ocean, the Arabian Sea, the Bay of Bengal and the Gulf of Siam. All the oceans are connected with one another.

There are six oceans in the world. They are the Pacific, the Atlantic, the Indian, the Mediterranean, the Arctic and the Antarctic. The major ones are described here.

(1) *The Pacific Ocean*—It is the largest as well as the deepest ocean. It nearly occupies half of the earth's surface. It has an average depth of 14,000 ft. This ocean is generally bordered by steep sides and a belt of mountains and volcanoes. The Pacific border is characterised as having a series of deeps. The remaining parts of the ocean is generally flat. There are protruding islands, generally coral islands, built sometimes on the summits of sub-terranean volcanoes.

(2) *The Atlantic Ocean*—It is of lesser extent in area than the Pacific. A prominent ridge, known as the Mid-Atlantic Ridge occurs in the middle part of the Atlantic floor. On either side of this ridge there are deeps. Number of islands in the Atlantic is fewer.

The Mid-Atlantic Ridge is due probably to mountain building activity and the Pacific deeps (average depth 12,000 feet) are of recent origin as evidenced by frequent earthquakes.

(3) *The Indian Ocean*—This is enclosed on its three sides by continental masses. The floor of this ocean is also bordered by narrow deeps. There are coral islands in the

Indian Ocean but fewer than those in the Pacific Ocean.

Classification of the Seas :

Three distinct classes of seas have been recognised. They are :—

(1) *Epeiric seas*—The word *epeiric* has come from the Greek word *epeiros* meaning a continent. Epeiric seas are those which are nearly surrounded by land masses, for example the Baltic Sea.

(2) *Marginal or shelf seas*—These seas are on the continental shelf with open connections with the oceans, for example—the Yellow Sea of China.

(3) *Relic seas*—These were formerly parts of oceans, now cut off by the uplift of land masses, for example—the Caspian Sea.

Composition of Sea Water :

Sea water contains on an average 3·5 p.c. of salt, which consists mainly of NaCl (nearly 80 p.c.) besides some amount of $MgCl_2$, $MgSO_4$, $CaSO_4$, K_2SO_4, $CaCO_3$ etc.

Among other minor constituents are compounds of F, B, As, I, P, Si, Cu, Fe, Pb, Ag, Au, etc. Besides there are also O_2, CO_2 & N_2 in solution with the sea water. From the geological point of view the important constituents are $CaCO_3$, SiO_2 and the dissolved content of CO_2 and O_2. The source of the mineral substances is the land surface and they are brought by rivers in solution and in suspension. Some of the salt materials are taken up by marine organisms for the building up of their shells and as food materials. The p.c. of NaCl however goes on increasing. Sea water therefore becomes more and more saline each year.

Characteristics of the Ocean Floors—The submarine topography is not quite clear due to the lack of observation. Recently the floors of the oceans have been tried to be surveyed by means of sound waves. Such surveying is called *sonic surveying*. In this method sound waves are sent to the ocean floor from an exploration ship. These waves are reflected and are again received by instruments on board the ship. This gives the depth at that place. The position of the ship is known from marine survey maps. This method of exploring has widened our knowledge of the ocean floor. From this we have come to know that the floors of the oceans are irregular and are marked by rises and deeps. The oceans do not attain their greatest depth at the middle of the floor but near their borders. The floors are generally like the shells of a tortoise.

Depth Zones and their Characteristics—

The following zones in oceans have been recognised according to depth.

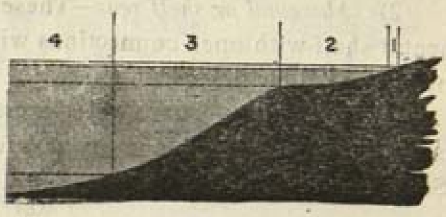


Fig.—24
Depth zones

(1) *Littoral zone*—This includes the area between the levels of the high tide and the low tide. Deposits here are the coarsest and the sorting action of the waves is most conspicuous. Deposits are mostly collected from the continental land masses and are called *terrigenous* (derived from land) deposits. Animals which can live exposed to the air for some time live here. Width is generally 2 miles from the land towards the sea. Total area is about 60,000 square miles. It is also called the *strand*.

(2a) *Neritic zone*—The ward neritic has been derived from the Greek word *neritos* meaning a mussel. This zone includes the area between the tide mark and the continental shelf margin. Total area is nearly 10,000,000 square miles. It is a zone of calmness as well as activity. Wave action and sorting of sediments are conspicuous.

(2 b) *Continental shelf zone*—Depth varies from 350 ft. to 600 ft. and the distance from the land varies from 20 to 200 miles, average 75 miles. Average inclination towards the sea is 10 ft. to a mile. Most of the terrigenous sediments are

deposited here. In the upper part sunlight can penetrate easily and temperature changes with seasons and latitude. Wave action is noticeable, and salinity and turbidity vary also. In the upper part algae and molluscs thrive best. The deposits here vary from gravels or pebbles to finer sediments. This upper part is known as the *Laminarian zone* from the preponderance of the algae Laminaria. In the lower part there is an abruptness in the temperature change. Penetrability of light becomes less and with it aquatic plants also become rare. At the lowest limit finer sediments of mud, lime etc. are deposited. Corals flourish in this zone and coral islands are notable features of this zone. Brachiopods are also abundant.

(3) *Continental slope zone*—The area is nearly twice that of continental shelf zone. Depth is from 600 ft. to 3000 ft. No light can penetrate except in the uppermost part. (Light can penetrate up to a depth of 650 ft. in open oceans). No wind action is felt. Temperature is low and water pressure is very great. The sediments here are very fine. Black, blue and green mud, coral mud, volcanic mud etc. are found here. Deep sea deposits like oozes are also seen in the lower part.

(4) *Abyssal zone*—This includes the zone of deep sea floor. Depth is from 3000 ft. to 12,000 ft. (or more in particular areas).

Investigations of the rocks of the ocean floors and its deposits are carried by means of a device called *bottom sampler* invented by Piggot in 1934. A long (generally 10 ft.) metal tube attached to a gun is lowered from an exploration ship to the sea bottom. On reaching the bottom, the gun fires and the tube is dipped into the floor of the ocean. Then the tube automatically closes and is raised up to the ship. Thus a sample of the deposits and rocks of the ocean floor is brought to light.

With the help of this instrument it has been found that the deep ocean floor is characterised by a slimy, mud-like deposit called *ooze* and *red clay*. The oozes are formed from the remains of minute marine animals and plants. There are many types of oozes named according to the name of the animal or the plant supplying the materials for its formation. These are :—

(a) *Radiolarian ooze*—This type of ooze is formed from the minute shells of Radiolaria (a minutemari ne animal of the phylum Protozoa). The shells are made up of silica. When the animals die, the shells sink to the bottom of the deep sea and collect there. Gradual accumulation of the shells leads to the formation of the ooze. The Radiolarian ooze accumulates at an average depth of of 18,000 ft. and is found generally in the deep and warm parts of the Pacific and the Indian Oceans.

(b) *Foraminiferal ooze* (*Globigerina ooze*)—The foraminifera is another type of marine animals (of the phylum Protozoa). They are minute and their shells are composed of calcium carbonate. When these tiny animals die their shells go on sinking but generally a great portion of these shells go into solution before reaching the sea bottom. The average depth of Globigerina (the chief ooze-forming foraminifer) ooze is 12,000 ft. The Globigerina generally abounds in tropical or temperate open oceans. The Globigerina ooze is the most abundant type of ooze and is specially found in the Atlantic Ocean.

(c) *Pteropod ooze*—The Pteropod or the sea butterflies are floating molluscs (Gasteropods). They thrive well in shallow, warm and open oceans and their shells are composed of calcareous materials generally aragonite. The Pteropod ooze is also characteristic of the Atlantic floor. The accumulation of Pteropod ooze is at a lesser depth than that of the previous one. Pteropod ooze accumulates generally at a depth of 10,000 ft. nearly.

(d) *Diatom ooze*—The diatom is a minute plant and lives in quite shallow water as the penetrability of the sun-light is up to a depth of 650 ft. The shells of diatoms are formed of silica. Diatom oozes are found in high latitudes generally.

Red clay—This is another type of abyssal deposit. It is formed of wind-borne volcanic and land materials, meteoric dust, subterranean volcanic products and iceberg-borne materials. Subordinately manganese oxide, silicate materials and organic remains are also found. The red colour is due to the oxidation of iron materials. Its accumulation occurs at the deepest part of the ocean.

Coral Reefs :—

These are island like structures made up of organic deposits which are abundant in tropical and sub-tropical oceans. In the Pacific Ocean coral reefs are abundant but they are also found in the Indian Ocean. These reefs are structures built around islands, sometimes volcanic peaks, by corals and other lime-secreting minute animals. The corals build protective shells of calcium carbonate around their bodies. When they die, the shells sink and accumulate on the sea bottom. Corals live in swarms in shallow, clear and warm water of the oceans. Millions of millions of these animals die to supply the calcareous material to form the reefs. Coral families build structures in plant-like fashions and the inter-spaces between the branching coralline structures are filled up in due course of time by the deposition of calcium carbonate either by other lime-secreting organisms like the nullipores (algae) or molluscs, or by the debris broken by the sea waves. Gradually an island-like structure is built up which is exposed only at low tides. Coral reefs can not grow above the low tide mark for the minute animals can not stand exposure to the atmosphere for a great length of time.

The formation of coral reefs requires the following conditions.

(1) The water must be warm generally above 68° F (or 20° C). Coral reefs are therefore generally found between 30° N and 30° S latitudes.

(2) The water must be clear. Corals can not thrive in muddy water.

(3) The water must be shallow generally 150 ft. or less.

Types of coral reefs—There are three types of coral reefs.

(i) *Fringing reefs*—These are such as are built close to the main islands or volcanic cones and are laid bare only at low tides. They, so to say, fringe upon the land and are like platforms.

(ii) *Barrier reefs*—These are built away from the mainland like barriers and enclose a body of water between the mainland and themselves. For example the Great Barrier Reef off the east coast of Australia.

(iii) *Atolls*—These are circular reefs enclosing circular lagoons. The Bikni Atoll near the Hawaii Islands, famous for atom bomb experiments, is a famous example.

Origin of Coral Reefs—Corals generally thrive near an island or a volcanic cone where they get some protection against the ocean currents. Reef-building corals gradually construct a platform-like structure near the island or the volcanic cone. In this way a fringing reef is built up. The barrier reefs or the atolls generally point to a depth of formation where no coral can live. As already pointed out corals can only live in shallow water, generally less than 150 ft. deep. But barrier reefs and atolls, rise from more than 150 ft. of depth. Hence their formation can evidently be due to either the submergence of the ocean bottom or the rise of the sea level keeping pace with the reef building.

Subsidence Hypothesis—This hypothesis put forward by Darwin and Dana postulates a submergence of the sea floor. Suppose that a fringing reef has been built about the summit of a volcanic cone and suppose that the volcanic cone is subsiding owing to diastrophic movements of the sea floor. As subsidence of the volcanic cone continues, the corals migrate outwards and upwards. (The growth of coral reef is rather rapid nearly 1 ft. in 10 years). Fringing reef will thus pass on to a barrier reef enclosing a body of water between the reef and the island. Ultimately when the volcanic island will disappear totally, the barrier reef will be converted into an atoll with a circular lagoon inside.

This idea nicely explains the phenomena associated with coral reefs, and submergence of the sea floor is a possibility and actually occurred in geological history. One of the defects of this idea however is that it fails to explain the flatness of the lagoon floors inside the barrier reefs and atolls.

Glacial Control Hypothesis—The other possibility, namely the rise of the sea level has been suggested by Daly. He says that the sea level is rising following the melting of Pleistocene glacial cover. Daly notices that the reefs are steep walled. They are built on submarine platforms which he thinks to be the platforms of marine erosion from pre-glacial islands or volcanoes. The reefs are narrow and hence young, which according to Daly, is due to their post-glacial origin. The defect of this idea however is that it can not explain the growth of coral reefs for more than 325 ft. which is the estimated rise of sea level following the Pleistocene deglaciation.

Borings at different coral islands in the Pacific Ocean have not yet yielded any conclusive evidence in favour of any one of these two above-mentioned ideas. None of them alone is able to explain all the features of coral reef-building but they together combine to explain all these.

Solution Hypothesis—It was proposed by Murray and Agassiz. This explains the formation of barrier reefs as a result of solution of the inner parts of the initial fringing reefs. The corals grow outwards and sea-wards as food materials are abundant there. As a result of this outward and sea-ward growth, the fringing reefs grow wider, but the solution of calcareous material from the inner side removes the connection between the reef and the main island around which the reef grows. The fringing reef thus becomes a barrier reef with a body of water inside. The atolls have grown in a similar way around a submarine platform formed by marine denudation. This idea is unacceptable on account of the fact that the enclosing body of water is saturated with calcareous material, and hence any more solution of calcareous material is not possible by this water.

Marine Destruction, Transport and Construction :--

(A) *Destruction*—The destruction of the sea shore is mainly effected by sea waves and currents though it is largely aided by tides. Wave action is only perceptible to a maximum depth of 700 ft. The depth factor is important in marine erosion. The waves generated by wind are dashing against the shore constantly and bit by bit the shore is eroded. This attack by sea waves is seen everywhere on the coastal region but it depends upon the following factors :—

(i) *Nature of the coast*--If the coast be precipitous, then the wave action is violent. Unobstructed the sea waves dash against the shore directly and a great amount of coastal rock is eroded by such impacts. In a shallow sea over a low-lying coastal plain the wave movement is much obstructed before it reaches the shore. Hence the wave action is less violent in such coastal areas.

(ii) *Nature of the coastal rock*--Naturally if the rock be hard then it is eroded with less rapidity and if it be soft comparatively then it is eroded with more rapidity. Igneous and harder metamorphic rocks have thus chances of surviving to a greater date than the sedimentary rocks. Then the nature of the individual mineral is also to be taken into account. Rocks consisting of soluble materials are eroded easily. In the case of sedimentary and some banded metamorphic rocks, the stratification and banding is an important factor, that is, whether it is inclined, horizontal or vertical and if inclined, whether it is towards the sea or away from the sea. Other factors remaining equal, horizontal beds are eroded away more easily than the vertical beds and in the case of inclined beds those which dip away from the sea are eroded more easily.

(iii) *Presence of joints and fissures in the rocks*—The presence of joints and fissures greatly facilitates the erosive action of sea waves. When the sea waves dash against the jointed rocks the air inside the joints and fissures is highly compressed due to the sudden blow of the waves. As a result the inside air exerts pressure in all directions and acts like a wedge. This highly accelerates the erosive action of the waves. This also facilitates the solution of materials by allowing sea water to percolate into the rock.

(iv) *Presence of rock particles with the waves*—When the sea waves, armed with hard rock fragments, dash against the coastal rocks, a great deal of abrasion is done. These fragments of rocks are thrown against the shore wearing much of the coastal regions. In this process of dashing, the particles themselves are also worn down no doubt.

(v) *Chemical action of sea water*—Sea water ordinarily can take into solution many substances of the coastal regions. The water becomes a much better solvent when it contains some dissolved materials in solution.

(vi) *Wave strength*—The more the strength of the sea waves, the more is the marine erosion.

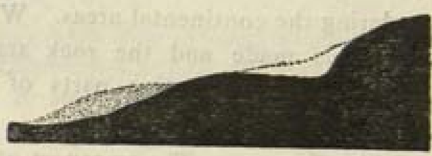
Since the formation of continents and oceans, the above factors are operating and the result is the gradual retreat of the coasts and the development of irregular coast lines bordering the continental areas. Where the rock is hard, less erosion is made and the rock stands projecting into the oceans. Such projecting parts of land are called *head lands or promontories.*

(B) *Transport*—The transport of the products of erosion is also effected by ocean waves and currents. These products of erosion are carried in two ways—(i) in suspension by drifting and (ii) in solution.

Suspended particles as well as those on the bottom of the shore zone are carried further off by means of sea waves. After the breaking up of the coastal rocks the waves try to carry them towards the sea. They are lifted and are carried off-shore. The long shore currents try to arrange the sediments parallel to the shore. They thus build *spits or bars* across the coastal region enclosing a lagoon (c.f. Lake Chilka or Lake Pulicat). There is a conspicuous sorting action of the sediments by the wave action. The finer particles are carried away and the coarser particles are left on the beach to form *beach* *shingle*. The coarser sediments, in course of time, are ground fine by the abrasion caused by waves and are then carried away. The terrigneous deposits are not found in deep sea bottom. They are only to be found in continental shelf and margins of the continental slopes.

The materials in solution are also carried further off. Sometimes by reacting amongst themselves i.e. other salt solutions, they may be precipitated, but more often minute organisms, animals and plants, extract certain minerals from them to build their protecting shells or tissues. $CaCO_3$ and SiO_2 are thus utilised by marine organisms.

(C) *Construction*—As the waves dash against the shore, it is eroded away and gradually retreats after supplying rock debris to be handled by the sea waves. A cliff or an escarpment is thus formed. This cliff is called the *wave cut cliff* because it is the work of the sea waves. The products of erosion fall immediately below it and form a more or less narrow flat region adjacent to the shore-line. This is the *sea beach*. The debris from here is carried further off. The coarser sediments are left on the beach to form beach shingle. Finer ones are carried away. As the wave cut cliff retreats, another flat region is formed immediately below the beach over which the water is very shallow, generally 10 to 20 ft. deep near the shore but gradually deepening off shore. This platform-like feature which is the effect of destructive action of the sea waves is called the *wave cut bench or the plain of marine denudation*.



Fig—25
Shore profile

The materials that are carried off shore are deposited near the farthest end of this bench and gradually at its sea-ward margin another more or less flat region (though sloping away from the shore) is built up. This platform-like feature which is the effect of the constructive action of sea waves is called the *wave built terrace*.

The profile from the wave built terrace to the wave cut cliff i.e. a transverse section across a shore is called a *shore profile*. This profile changes gradually. The retreat of the wave cut cliff gives more materials to handle and the wave cut bench widens and the deposition of the materials at the margin of it makes the wave built terrace wider also. Thus the sea waves have two functions to perform, to erode the coastal region and to transport the debris further off. If at any time the waves perform more erosion, more products of erosion will be there to be handled. Consequently immediately after the erosion, more of the energy of the sea waves will be spent in moving the rock materials and less in erosion. Thus there is a balance between marine destruction on the one hand and construction on the other. If the shore region is steep, it is exposed to the full vehemence of the sea waves and consequently the cliff retreats and the region becomes flat. If the region, on the other hand be flat there will be deposition of the beach material near the shore and consequently the shore region will become steep. Thus an equilibrium is maintained at a late stage of marine destruction and construction. When this balancing stage is reached, the shore profile is called a *profile of equilibrium*.

Shore features caused by marine erosion—Due to under-cutting by the sea waves and presence of joints in weak coastal rocks marine erosion sometimes produces a cave-like feature at the base of the wave-cut cliff which is called a *sea cave*. Sometimes such caves proceed landward to a considerable extent producing a *sea tunnel*. The under-cutting and compression of air by the impact of the sea waves cause the blowing of a part of the roof of a sea cave. Sea water, then cutting the caves, spray out from such holes. Such holes on the roof of the sea caves are called *blow holes* or *gloups* and sea caves having such holes are called *spouting holes*. Sometimes two sea caves from two sides of a narrow promontory join by undercutting it and they produce a gate-way like feature called a *sea arch.* When the roof of a sea cave collapses, an inlet of the sea is caused. When the roof of a sea arch collapses the far off pillar stands in the sea. This pillar-like structure standing in the sea is called a *stack*. Stacks are also caused by marine erosion in vertically jointed rocks. When the coastal rock is weaker, erosion is very pronounced and a small inlet of the sea is made which is called a *core* or a *bay*.

Other features of marine erosion are the wave cut cliff, wave cut bench etc. which have been already described.

Shore features produced by marine construction—Sometimes long-shore currents produce ridges from the products of marine denudation by the dumping up of the rock fragments torn off from the wave cut cliff or brought by rivers. By gradual addition of rock fragments the ridges grow across the shore and ultimately rise above the sea level. If the ridge be straight and if it communicates freely with the ocean water at its far end, it is called a *spit*. If the ridge be curved it is called a *hook*. If the far end of the ridge is not free and there is no free communication with the sea, the ridge is called a *bar*. Bars either generally start from one promontory to another or connect near islands to the main-land.

Classification of the Shore Lines :—

Generally there are two types of the shore lines—one is the shore line of emergence and the other is the shore line of subsidence. Sometimes a complex type is also seen which is a combination of the two.

(i) *Shore line of emergence*—Uplift of the sea bottom or a gradual fall of the sea level is the cause of such coast lines. Uplift of the sea bottom may be caused by the vertical movements of diastrophism. Such shore lines newly emerged from beneath the sea, will show raised beaches, (PL—18) wave-cut benches or wave-built terraces. Water is quite shallow near such shores. In the intial stage of evolution of an emerged shoreline, the waves drag the sediments over the shallow bottom and deposit them at some distance from the shore forming off-shore bars and converting the sheltered water back of them into lagoons. Gradually the lagoons tend to be filled up by sediments from the main-land. The destructive action of the sea waves is then confined to the sea-ward side of bars. As a result of erosion the bars get narrower and move land-ward. Ultimately the bars are totally eroded and the shore is exposed to the destruction by sea waves. Shore lines of emergence are at present rare. Deglaciated parts of Finland and Norway show this type of shore line at places.

(ii) *Shore line of submergence*—This type of shore line is very irregular with bays and head lands. Fiords, which are drowned glaciated valleys, are conspicuous features of such shores in glaciated areas. Projections of hard rocks and submerged forests near the coasts are also at times seen. The intial stage in the erosion starts on the head lands and island-like projections. Gradually sea caves, blow holes sea arches, stacks etc. are formed in succession and finally the roof collapses and a narrow inlet is formed. Then bit by bit head-lands are eroded away, so also the islands. The products of erosion are carried away and deposited at some distance to form wave built terraces. Long shore currents also build spits, hooks and bars. Finally these are also eroded away and the shore profile is then converted into a profile of equilibrium. Shoreline of submergence is a commoner feature.

Complexities arise in shorelines due to a combination of the above two types. Some also point to no alteration of the sea-level at all.

Protection of the Coastal Region against Marine Erosion :—

This is an important problem to the engineering geologists. The protective measures to be adopted depend on the study of the wave action at a particular place. One of the effective methods to check coastal erosion is to construct barriers, known as *groynes*, across (transverse) the sea shore. This prevents the carrying away of beach material and thus new surfaces of the coast are not left exposed to wave action. Long shore currents carrying sediments are also obstructed and then they deposit the material to widen the beaches. One of the difficulties with groynes is that though they check erosion at a place they accelerate erosion at another place. Sometimes walls are constructed parallel to the shore. The waves dash against the walls and their velocity is checked. The walls are however liable to be under-cut. Sand heaps are sometimes very effective in checking the impact of the sea-waves.

Coast Line of India :—

The coast line of India is more or less regular with a very few inlets and headlands. The apathy of the Indians to sea-going is in a measure attributable to such unindented coast-line.

The western coast is called the *Konkan Coast* in the northern part from Goa to the Gulf of Cambay and the southern part is called the *Malabar Coast*. On the Malabar coast there are several lagoons. In Kerala they are called *kayals*. This narrow coastal tract supports a good plantation owing to the heavy rain-fall due to the south-west monsoon. The Malabar Coast has a shallow submerged plain—a wave-cut bench or a plain of marine denudation. The narrow bench abruptly deepens. The Malabar Coast seems to be a faulted region.

The north-western coast is called the *Mekran Coast*. This reveals some parallel ridges separated by valleys. This coast also seems to be a faulted area. This is in West Pakistan.

The western coast as a whole is rocky and deep sea water lies close to the shore. Karachi (Pakistan), Bombay, Goa, Cochin are good harbours on this side.

The eastern coast has a wider coastal plain. It is called the *Karnatic Plain*. The water near the shore is shallow. The southern part of the east coast is known as the *Coromandel Coast* while the northern part from the river Kistna is called the *Golkonda Coast*. Madras and Vizgapatam are two harbours on this coast while Calcutta is an inland harbour on the mouth of the river Hooghly. The eastern coast of the Bay of Bengal seems to be submerged, perhaps due to faulting. There is a long north-south running ridge called the *Andaman Ridge* passing through the Andaman Islands, and continuing into the Arakan Yomas after submergence into the bay. The volcanic Narcondam and Barren Islands are separated from this Andaman Ridge by a valley-like depression. There are two more ridges parallel to the Andaman Ridge and west of it. The second is the *Carpenter's Ridge*, and the depression between them is called the *Investigator Deep*.

Permanency of Oceans and Continents :—

Formerly it was believed that continental blocks and ocean basins are unstable in the sense that they have frequently inter-changed their postitions. Closer examination has revealed-that neither deep ocean floors have formed land masses, nor the continental blocks have formed deep sea basins at any time of the earth's history particularly after the Archaeozic time although marginal parts of the continents have been inundated by oceanic transgressions, and shallow parts of the continental shelves of the oceans have formed land masses at intervals. The evidences in favour of this idea are :—

(i) Sonic surveying has nowhere revealed any submerged continental block at deep oceanic depth.

(ii) Deep sea oozes have nowhere been found on the surface of the continents to form sedimentary rocks with exception of certain deposits in some oceanic islands like Barbados, Borneo etc. The sedimentary rocks like sandstone, mudstone and limestone are formed on the shallow continental shelf of the oceans. The included fossils also reveal shallow water organisms. These rocks are seldom to be found on distant oceanic islands.

(iii) Sinking of light sialic continental blocks in heavy oceanic simatic layer is rather a physical impossibility. Small areas may however sink down but sinking of vast continental sectors seems to be absurd. Similar is the case with the emergence of deep ocean floors.

One thing is to be remembered in this connection that this idea of permanency of oceans and continents does not go against the idea of continental drift, for the former idea deals with the vertical movements of the continental areas and oceans while the later deals with the horizontal sliding only.

Marine Transgression—Continental borders have been periodically submerged by the invasions of the seas, thus converting these marginal areas into epicontinental seas. Such temporary invasions by seas are called marine transgressions. The immediate cause of this is either the decrease in the capacity of the ocean, as a result of which some water will evidently spill over, or increase in the volume of sea water. The ultimate causes are the following :—

(i) Melting of ice sheets—This process releases a huge quantity of water which increases the volume of ocean water and thus permits a rise of sea level.

(ii) Elevation of sea bottom.

(iii) Sinking of the continental masses.

The second and third processes are due to diastrophic movements. The idea of Thermal Cycle put forward by Joly explains such changes. The deposits formed by transgressions on submerged continental border areas present some peculiarities. These deposits are called coastal system of deposits. The Upper Jurassic rocks of Cutch and the Upper Cretaceous rocks of Trichinopoly are such deposits. These areas of India were transgressed by oceans during the periods mentioned.

Sometimes after each marine transgression the invaded water recedes and this phenomenon is called *marine regression*, the causes of which are just the opposite to those of marine transgression.

CHAPTER VIII

UNDERGROUND WATER

The water that is obtained from atmospheric precipitation is called *meteoric water*. Water may also be of magmatic origin. This magmatic water is also called *plutonic water* because of its deep-seated origin. Though this magmatic water rises through the minute capillary pore spaces to the surface, its percentage is quite small compared to the water derived from the atmosphere. The water that is entrapped in sedimentary rocks during their formation is called *connate water*.

The water that falls upon the surface is divided into three parts. One part is quickly evaporated, another flows over the surface of the earth and the third sinks below. The part which flows over the surface as stream water is called the *immediate run off*. The part that sinks down is known as the *subsurface* or *underground water*. A part of this underground water again comes out upon the surface through springs, wells (artesian or tube or ordinary) etc. This constitutes the *delayed run off*. A considerable part of the underground water reaches the sea through underground circulation.

The relative proportion of these three parts depends upon (i) climate, (ii) topography and (iii) rock character of a region.

(i) *Climate*—If the climate be humid, evaporation will be slow and the water will flow as run off or underground water. In such a climate the run off may come up to 50 p.c. of the total precipitation. In arid climates, evaporation predominates and run off and ground-water decrease in amount. As the precipitation is small in such areas, run off is very little, nearly 20 p.c. of the total. On an average nearly 30 p.c. may form run off.

(ii) *Topography*—In a steeply inclined surface run off will be greater than other processes whereas on a plain area or more conspicuously in a depressed area underground circulation of water will predominate.

(iii) *Character of the rock*—This factor also derermines to a large extent the relative proportion of three parts. The most influencing factors in this respect are—(a) porosity and (b) permeability.

(a) *Porosity*—It is the amount of open space in a rock body. Hard and compact rocks like the igneous varieties, and metamorphic rocks like quartzites etc. have very little open space in them. Consequently on an igneous area run off will be greater than on a sedimentary area. It is to be remembered that fissures and joints will also come under the open space while determining the porosity of a rock.

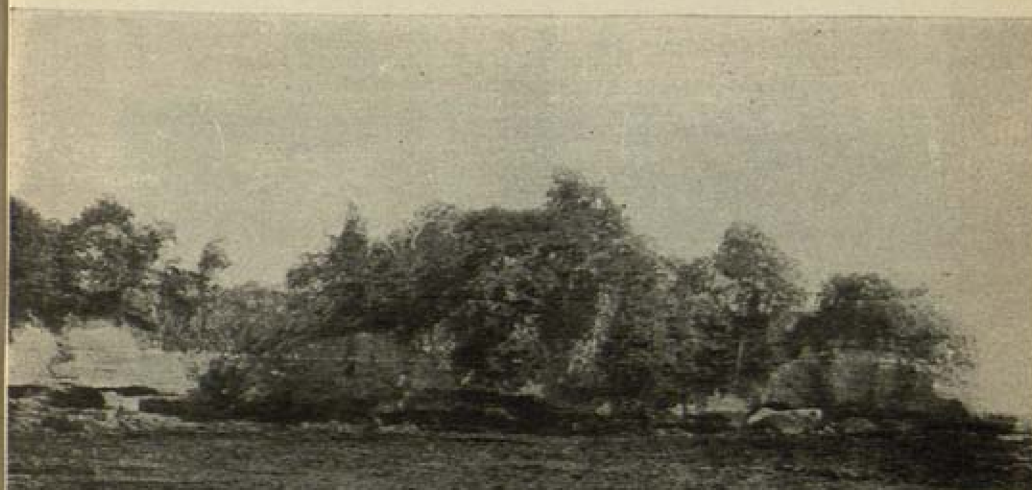
(b) *Permeability*—It is the property by virtue of which water or any solution can pass through the rock possessing this property. Rocks possessing this property of allowing the passage of water or solutions are called permeable rocks, such as sandstones. Those which do not possess this property are called impermeable rocks such as shales. Over a country of permeable rocks therefore, run off will be little in comparison to the underground water circulation, whereas over a country of impermeable rocks run off will be greater in comparison to the underground soaking.

Effect of vegetation on run off—Vegetation exercises a strong influence on the surface run off. It has been found that forest areas have greater rainfall than the areas devoid of forests. Forests produce a cooling atmosphere and vegetation can retain a considerable proportion of moisture. Other factors remaining equal, the amount of percolation will be less and hence run off will be greater in such forest covered areas, than in bare areas.

Apart from evaporation, run off and percolation, a part of the atmospheric precipitation is held by the vegetation and another part by the minerals and rocks in the process of weathering. Ordinarily this part will be negligible but at times the absorbed water becomes considerable.

Pl.—16
Hundru Falls

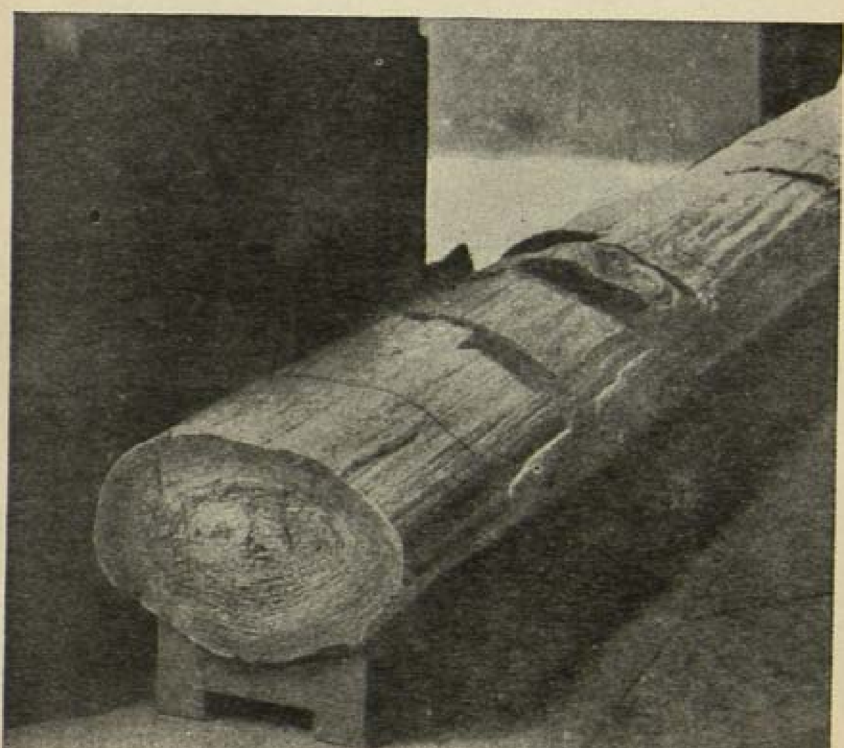
Pl.—17
Jonha Falls



Pl.—18 A raised coral beach of the south end of Henry Lawrence Island, Ritchie's Archipelago

(By courtesy, Director, G.S.I.)

Pl.—19 Calcareous growths in Htamsang Cave *(By courtesy, Director, G.S.I.)*



Pl.—20 Petrified tree, Kumarpur Railway Cutting *(By courtesy, Director (G.S.I.)*

Determination of (a) run off (b) evaporation (c) percolation :—

(a) *Run off*—It is determined by the discharge of all the rivers of an area.

(b) *Evaporation*—It is determined with the help of *Evaporation gauges.* These are tanks with a generally square yard of area and are left floating on large bodies of water. From the evaporation of water from the water surface of such tanks, evaporation at a place can be determined. The average annual evaporation in India is 60 inches.

(c) *Percolation*—It is measured by *Dalton gauges.* These are columns of ground-rock usually one square yard in area which are surrounded by water tight walls, both on the sides and on the bottom. Ths amount of percolated water flows to a measuring vessel and thus the percolation is determined.

Water Table and Zones of Aeration and Saturation :—

At a certain depth below the surface all the rocks are saturated with water which means that all the rock spaces are completely filled up with water. The upper surface of this saturated area is called *water table.* The water table, which is not a flat surface, follows roughly the topography of an area and is more or less parallel to it. Its form and depth are determined by rainfall and topography. The water below the water table is called the *zone of saturation.* The water between the surface of the earth and the water table is called *vadose water* and this zone is called the *zone of aeration.*

Fig—26

Water table and zones of aeration and saturation

Zone of aeration—The thickness of this zone varies with the depth of the water table. Below mountains it is quite deep and below low-lying areas it is quite shallow. Some times it may cut the ground surface near a very low-lying tract. Seepages, marshes and springs are common at such intersection places of the water table and ground level. Hence where the water table will be at a great depth, the zone of aeration will be thick, and when the water table will be at a shallow depth, the zone of aeration will be thin. In a zone of aeration two sub-zones are clearly recognisable. They are :—

(i) *The soil water zone*—Here the water is held by the soil and plants take water from this zone. Clayey soil has got great water retaining capacity while a sandy soil has got very little of it.

(ii) *The capillary fringe*—This sub-zone derives its water from the ground by means of capillary action and lies exactly above the water table. If the inter-spaces in a rock be minute, this zone will have a greater width as in shale whereas in sandstone, this zone is negligible.

Zone of saturation—This zone extends from the water table downwards to the place where all the open spaces in the rocks are completely filled with water. As the open spaces become negligible with the depth in the crust, the lowest limit of this zone is not far below the surface. Leaving the portion of connate and magmatic water, ground water generally becomes rare at a depth of 2000 ft. or 3000 ft. below the surface, although at some places water-bearing rocks have been found at a depth ot 6000 ft. below the surface of the earth.

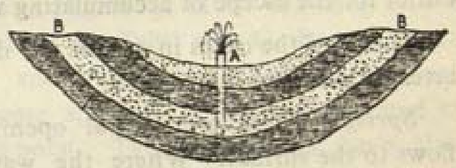
Perched or raised water table—In regions above the water table a lens-shaped body of rock with an upper concave surface may hold a body of water and may thus have a local water table. This water table is called the *perched or raised water table.*

Underground circulation—In the zone of aeration water flows mainly downward. The percolation is chiefly controlled by the forces of gravity, adhesion and capillarity. Gravity causes a downward flow of water. The movement of water always meets with some resistance from the friction of the rock surfaces. In previous beds like those of sand and gravel, the movement is rapid while in beds like those of shales the flow is practically at a stand still. The molecular forces of adhesion tend to retain the water in the interspaces of rock. By the capillary action some water is sucked up through the minute spaces of the rocks underground.

Wells—Supply of water can be obtained from the wells which are dug sufficiently deep to reach below the water table. In regions, where there is great fluctuation of water table due to summer and rainy seasons the depth of the wells should be made very deep, otherwise in the drier months of the year the wells will be dried up. Sedimentary rocks can yield water very easily whereas in igneous and metamorphic rocks, water prospecting is a difficult task. Successful exploration of joint planes, cracks, fissures and planes of schistosity or gneissosity may produce good sites for water supply. In this task the weathered rocks are more promising than the undecomposed rocks.

Aquifer—This means a water producing mass of rock.

Artesian wells—These are a special type of wells operating under special conditions. The name is because of the fact that the first of its kind was made in Artois in France in the 12th century A D.



Fig—27
Artesian wells

Suppose there is a permeable layer like that of sandstone overlain and underlain by impermeable layers like those of shale and suppose they are all in the form of a basin as in the above figure. Now at the outcrop of the sandstone layer water enters into it but it can not go out because of the presence of two impermeable layers on both sides of the sandstone. Water will therefore collect in the curved layer of sandstone. With gradual accumulation of water in this sandstone layer a sort of hydrostatic pressure will develop in the water of the sandstone. If now a bore be made through the impermeable layer to reach the permeable layer, water will at once flow up depending upon the well known hydrostatic principle that water finds its own level. Such a well is called an artesian well. It should be noticed that if the foot of the well on the surface (A) be lower than the outcrop of the sandstone (B), water will flow out on the surface automatically but if the foot of the well be at a higher level than the outcrop of the sandstone, water will rise up to a certain height in the bore but will not reach to the surface and has got to be pumped out. The outcrop of the sandstone, which is the aquifer here, is called the *intake or the catchment* and height of the column of water extending up from the upper surface of the water where the hole is made is called the *head.* A certain amount of loss of head is generally the case because of the friction to the flow of water in the aquifer and the hole. The requisite conditions for the formation of an artesion well are therefore—(i) presence of a permeable layer in the form of a basin overlain and underlain by impermeable layers (ii) sufficient water supply in the aquifer, (iii) absence of outlet for the escape of accumulating water.

Many of the oases in deserts are due to the pouring out of artesian water on the surface.

Springs—These are natural openings through which water flows to the surface. Where the water table is cut by the ground level, springs and more commonly seepages occur (see Fig—26).

Springs are also possible at the outcrop of an inclined pervious bed such as sandstone underlain by an impervious layer such as shale.

Fig—28

Spring

Springs are very abundant in mountainous regions where a valley cuts the water table as in figure—26.

These are the common hillside springs. From such springs sometimes a river may originate and the spring recedes by means of undermining.

Spring water contians some dissolved matter which is precipitated at the mouth of the spring. The more common dissolved substances are the bi-carbonates, chlorides and sulphates of Ca and Mg, NaCl, borax etc. Some gases like CO_2 and H_2S are also present. Some radium salts, Fe_2O_3, aluminium salts, potassium salts are also at times present. These dissolved impurities impart to the spring water some specific characters. The soluble bi-carbonates, chlorides and sulphates of Ca and Mg make the water hard and render it unfit for washing purpose and boiler feeding. The radium and other salts at times impart to the spring water some medicinal properties and such water is used as a remedy for skin diseases, gout, rheumatism etc. In Europe several such springs have been developed into so many spas. Though there is no regular and well-developed spa industry in India, certain springs are places of pilgrimage as for example Badrinath in Garhwal, Jumnotri in Tehri near Garhwal, Rajghir and Sitakund in Bihar and Vakreshwar in Birbhum district of West Bengal. In some springs the water is hot and at times reaches the boiling point. The hot springs have also been described in the chapter on volcanoes and volcanism (Chapter—XIV).

Presence of bromide and iodide salts in the water of Jwalamukhi in Kangra in the Punjab (I) and sulphur in the water of Vakreshwar in West Bengal and Thana springs of Bombay has been reported. The water of Manikarna in Kulu in the Punjab (I) is so hot that pilgrims even boil rice in it. The water of some of the springs of Panchmahals of Bombay is radioactive. The water of Dudkund near Bhuvaneshwar is white because of the presence of kaolin in it.

Indian springs – According to Dr. P. K. Ghose there are four major tracts along which the majority of Indian springs occur. They are :—

(i) *Bihar belt*—including a series parallel to the boundary of the coal fields area, and springs of Rajghir area and Monghyr district.

(ii) *West coast belt*—including Ratnagiri, Thana, Colaba and Surat areas of Bombay.

(iii) *Sind—Baluchistan (Pakistan) belt.*

(iv) *The Himalayan belt.*

There are two other minor belts—one in the Mahanadi valley of Orissa and the other in Chitagong district of East Bengal (Pakistan). Besides them there are some irregular occurrences in Birbhum and Darjeeling districts of West Bengal, in Sikkim and in parts of South India.

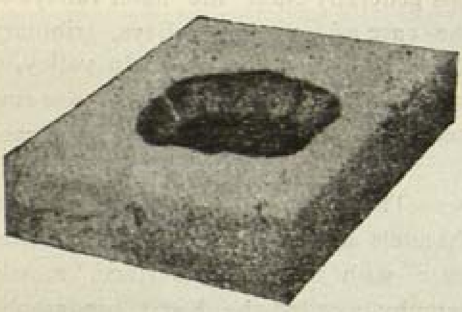
Geological Work of Underground Water :—

Erosion—Due to slow movement of underground water mechanical erosion is practically impossible. Indirectly it can do some erosion by producing land slides. When the soil in highly inclined surfaces becomes saturated with water, the water acts as a lubricating substance thus facilitating the flow of overlying rock mass. The result is the phenomenon of rock-slide which is disastrous in mountainous regions. The brought down rock mass is deposited at the foot-hill region and the deposit formed is called *talus or scree* deposits. Such a kind of flow of soil saturated with water is called *solifluction*. Some amount of mechanical abrasion is possible by underground stream flowing in underground channels.

Solution—Though mechanical erosion is negligible chemical erosion by underground water is highly important and compensates to a large extent the deficiency in mechanical erosion. The solution effect of the underground water is conspicuous in limestone regions or in some other easily soluble rock material such as the rock-salt. Limestone (including dolomite) is ordinarily insoluble in water but if the water contains CO_2 in solution, then it becomes a good solvent for limestone. The chemical process involved is the formation of bicarbonate of calcium which is soluble in water although carbonate calcium is insoluble in water.

The following important structures are formed as a result of underground solution of rocks.

(i) *Sinks*—These are basin-shaped or funnel-shaped hollows, of varying sizes, which are made in limestone regions by the underground solution. Surface water contains a good amount of CO_2 in solution. When this water percolates downward through limestone rocks, a good amount of rock is taken into solution. The result is the formation of a basin with consequent collapsing of the roof into it. As with the formation of Ca-bicarbonate, the dissolved CO_2 is lost, there is more solution near the surface than at depth. Hence naturally these sinks take the form of funnels but other shapes of sinks are also seen whose formation depends upon the structural peculiarities of the rocks. The formation of lakes, in such basins, specially when these basins are below the water table and the outlets are blocked so as not to allow the water to pass away, is possible.



Fig—29
Sink

(ii) *Caverns*—Small caves and underground channels are sometimes formed in limestone regions by the solution of underground rock by sub-surface water, but without the callapsing of the roofs. In these underground caverns and channels streams sometimes flow. The length of these caverns is variable. The Mammoth Cave in Kentucky has a total length of 30 miles underground.

(iii) *Solution valleys*—With continued solution underground rocks are undermined and at last the closely formed sinks and the underground channels are engulfed into a big valley. Such valleys are called solution valleys as their formation is due principally to underground solution. They can be distinguished from a river cut valley by the following facts.

(a) A river cut valley is V-shaped in transverse section i.e. with sloping valley sides, whereas the solution valleys have comparatively steep sides.

(b) The width of river valley is less variable than that of a solution valley.

(c) The river valleys contain water whereas solution valleys if formed above the water table may not contain water unless the outlets are clogged with sediments.

(d) The bed of a river valley is not generally strewn with such a heterogeneous mass of material as is the case with a solution valley.

(e) Tributary streams generally enter the main valleys at the same level but in the case of solution valleys, tributary valleys, if present at all, are hanging above the main valley.

(f) River valleys have no natural bridges whereas some rock remnants may be seen in the form of bridges in the case of solution valleys.

(iv) *Karst topography*—The close formation of sinks, caverns, underground channels and solution valleys produces a peculiar surface feature with a rugged surface, mostly waterless. Such a topography is called the Karst topography in German language. The formation of Karst topography is the result of underground solution of limestone rocks.

(v) *Stylolites*—When water containing CO_2 in solution percolates through the bedding planes of limestone rocks the more soluble parts are dissolved easily and the less soluble or insoluble parts are left as standing columns. Opposite columns, thus produced, interlock producing a zigzag line which is called a stylolite seam.

Transport—The dissolved substances are carried in solution by percolating water until they are deposited. Sometimes they are carried to seas or lakes through underground percolation. At times they are added to the stream water to be carried to seas or lakes. Thus the salinity of lake and sea-water

Pl.—21 Eroded Loess, Khuddera, Jalar Valley *(By courtesy, Director (G.S.I.)*

Pl.—22 Pindari glacier with moraines near Mastoli *(By courtesy, Director (G.S.I.)*

Pl.—23 Eratic blocks resting on Triassic Limestone

(By courtesy, Director, G.S.I.)

increases. Some part of the dissolved substances is also deposited in the interstices of the sediments and acts as binding material. The cementation work is very important in the formation of sedimentry rocks. $CaCO_3$, SiO_2 and Fe_2O_3, form good binding materials. These are often deposited in the rocks, specially calcium carbonate, to form sedimentary rocks. Other types of deposition are discussed below and the deposition from spring water has been discussed in the chapter on volcanoes and volcanism (Chapter—XIV).

Deposition—Apart from the cementation work which is caused by deposition of the dissolved substances in the interspaces of the particles of sediments, the deposition of these dissolved substances produces other distinct structures and features. The deposition depends on the following factors.

(a) *Loss of CO_2 and other dissolved gases*—It has been stated that the presence of CO_2 and other gases increases the dissolving power of water. When these are lost as a result of heating, evaporation or reaction, the dissolving power decreases and ultimately some amount of the dissolved substances will be thrown out of solution.

(b) *Evaporation of water*—As a result of the increase of heat or by atmospheric evaporation and consequent loss of some amount of water the concentration of the solution goes on increasing until a concentrated solution is formed. With more concentration, some amount of the dissolved substances is thrown out of solution and deposition of them takes place.

(c) *Decrease of temperature*—With the exception of a few substances which dissolve with the evolution of heat, increase of temperature increases the solubility of a substance and with the decrease of temperature solubility falls. When, therefore, the temperature of the solution falls as a result of loss of heat, some amount of the dissolved substances will generally be thrown out of solution.

(d) *Fall of pressure*—With the exception of a few substances which show expansion on solution, increase of pressure generally raises the solubility of substances and conversely decrease of pressure lowers it. Hence with fall of pressure, deposition of the dissolved substances is likely to take place.

(e) *Chemical reaction*—Deposition from percolating solution can take place as a result of the reaction brought about by (i) the mixing of two percolating solutions, (ii) by the action of gases upon solutions and, (iii) by the action of solid bodies upon solutions.

Some Depositional Features :—

(1) *Stalactites and stalagmites*—These are calcareous deposits of peculiar shape and size formed by percolating water containing $CaCO_3$ in solution. When such percolating solution containing $CaCO_3$ comes to the roof of a cave in limestone region, some amount of water and CO_2 are lost due to loss of pressure, fall of temperature and evaporation. The ultimate result will be the deposition of some amount of the dissolved $CaCO_3$ which will be left hanging as pendant-like masses. Such deposits are called *stalactites.*

Some amount of the solution will fall on the floor of the caves and upon it a dome-shaped or conical deposit will be formed. These deposits which are formed on the floor, are called *stalagmites.* With the increase in size of the two types there may be a union of the two and then a columnar deposit will result. These cave deposits are collectively called *dripstones* (PL—19).

(2) *Geode*—Sometimes cavities of rocks are filled up completely or partially by deposition from underground solutions. Generally, silica but rarely calcite, form such filling substances. The silica is deposited mostly in colloidal state and later turns to be agate (a crypto-crystalline form of silica). The deposition of amorphous silica layer by layer produces the characteristic banding, called *liesegang banding*, in agates. If crystals are deposited from solution, they extend towards the centre of the cavity. These crystals generally resemble the teeth of a comb and *comb structure* originates in this way. Such completely or partially filled cavities are called *geodes.*

Replacement—Sometimes percolating water takes into solution certain substances and deposits an equal volume of another material which the water was carrying in solution. Such substitution commonly occurs molecule by molecule so that the original structure of the dissolved substance is kept intact. Only there is effected a change of composing material. In such ways tree trunks are sometimes changed to solid hard masses which are called *petrified wood* (PL—20). Such petrifaction involves the solution (in some cases but not always) of the woody tissues and an equal deposition of siliceous material. The cellulose is thus replaced by silica but as the substitution takes place volume for volume, the woody structure is exactly preserved. More often there is the deposition of foreign matter without the solution of the woody tissues.

Sometimes the shells of fossils are replaced in a similar way. Besides silica, calcium carbonate, iron pyrites, oxide of iron, calcium sulphate, barium sulphate etc., form such replacing substances.

Concretions—The deposition around some solid particles as the nuclei produces concretionary masses. These are nodular in shape and often occur in sedimentary beds or upon the surface.

The Indian *kankar* is a concretionary deposit. It is formed by the deposition of calcium carbonate into nodular masses around some nuclei.

CHAPTER IX

WIND ACTION

Wind has got a pronounced effect on weather and as a result it influences rain and snow-falls which are again the prime factors in the geological work of streams and glaciers. By blowing over the seas, wind generates sea waves and hence is responsible for coastal erosion. These effects can be described as indirect effects of wind action. Apart from these indirect effects, wind also performs several other geological action in the form of erosion, transport and deposition of materials upon the surface of the earth. These can be described as the direct effects of wind action. This direct action is mainly mechanical in nature and is clearly seen in arid deserts and semi-arid regions, where vegetation is sparse, and on bare coastal regions. In humid regions however the effect of wind action is very obscure for there is plenty of vegetation in such regions which covers the surface from wind action. The intersticial moisture also has a binding effect, thus obstructing the wind action.

Geological Action of Wind :—

Wind action can be divided into three parts—(1) erosion (2) transport and (3) deposition.

Wind erosion again consists principally of three processes. (a) *Deflation* which means the blowing away of rock particles by wind force. The word deflation has been derived from the Latin verb *deflare* meaning 'to blow away'. (b) The blown particles strike against upstanding masses and cause erosion by the mechanical wearing of the rocks. This is the *wind abrasion.* (3) The blown particles themselves are also worn round by the impact of other particles. This process is known as *attrition.* They all add to wind formed products.

Deflation—This causes removal of the loose particles. In coastal regions particles of the beach sand are dried during the recession of the sea water at low tides and wind carries the dried particles inland from the coastal regions. It has been calculated by Sir T. H. Holland and Dr. Cristie that nearly 130,000 tons of salt particles are carried annually from the Rann of Cutch region by the south-west monsoon towards Rajasthan.

In all these areas wind action is pronounced only on loose particles or weakly cemented or extremely weathered rocks. When wind blows a huge quantity of fine dust particles is lifted up and this covers the sky creating a suffocating atmosphere. The blowing away of the loose particles from the ground causes depression on the surface and in desert regions such depressions turn to be lakes after heavy showers of rain, though temporarily. There is thus an excavatiug action of wind on the ground. There is however a limit to this deepening by wind. The base level of this process is the water table of the area and when this is reached, blowing away of loose particles altogether stops. It is to be remembered however that with the erosion of the ground, the water table also tends to go down.

Deflation is a formidable menace to cultivable lands. Judicious planting of trees or fencing can alone arrest this destructive process. Factors aiding deflation are the absence of vegetation, absence of moisture in the interspaces of rocks, looseness of the rock particles and the high velocity of wind.

Wind abrasion—This effect is illustrated by artificial sand blast produced on smooth and clear surfaces when these surfaces get frosted appearance. The loose particles that are blown away by wind form good eroding agents. These particles strike against the exposed bed rocks in arid areas. As a result of this abrasion a great deal of erosion is done on them. The bed rocks are spotted, grooved and polished. Wind abrasion depends largely upon the character of the blown rock particles and the bed rock. Ideally the effects will be at their maximum when (i) the blown particles are hard, (ii) the bed is soft and (iii) the velocity of wind is great. Rocks consisting of hard and soft parts get differential abrasion and a honey-comb structure is produced.

One of the conspicuous structures produced by wind abrasion is the formation of pedestal rocks. These are curious features with wide rock caps balancing on narrow columns. These structures are produced by wind abrasion on upstanding rock masses. As the blown particles are not carried higher, lower regions of upstanding rock masses are only abraded and undercut. This makes the foot regions slender while the head regions remain more or less untouched. The ultimate structure is a wide rock cap standing on a slender rock column. Such rock columns are called *pedestal rocks*.

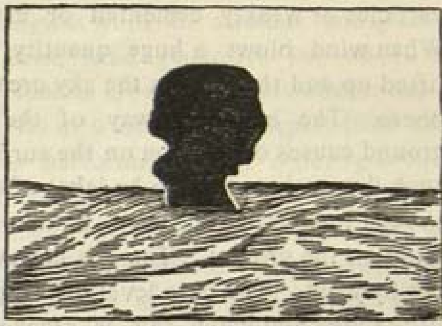


Fig.—30
Pedestal rock

A peculiar product of abrasion is the facetted and angular rock fragments which are called *ventifacts* meaning 'made by wind.' These are also known by the German name *dreikanter*. Wind blowing in a particular direction cuts a slightly curved, more or less flat surface on a rock fragment. When the direction of the wind changes or when the rock fragment rolls to another side then another face is cut by wind abrasion. In this way several smooth faces are developed on the rock fragments which meet at some angles with each other. In this way ventifacts are produced. Ideally ventifacts consist of more or less three equal sides. Harder rock fragments and generally quartz pebbles form ventifacts.

Sometimes wind abraded rock fragments show peculiar black coated polished surfaces. The black substance is manganese oxide which is derived from the interior of the rock.

The natural effects of wind abrasion are also seen in the frosting produced on pane glasses of houses on coastal regions and abrading effects on wooden telegraph posts.

Attrition—The rock particles not only abrade the exposed bed rocks but they themselves are also abraded by colliding against one another. This produces a rounded appearance of the individual fragments. This is because of the fact that the rock particles have chances of getting equal abrasion from all sides while on transit. The greater velocity and the greater length of transit are also contributing factors. Rounded desert sand grains are often called *millet seed sands* because of their resemblance with millet seed grains. Along with others this characteristic of the individual grains of rock particles in a sedimentary rock like sandstone betrays the history of its formation. The roundness produced can easily distinguish a wind-formed sandstone from a river-formed sandstone because in the latter case individual grains will not be perfectly spherical.

Transport—The transport of the loose particles is also effected by the velocity of wind. As the wind action is prominent in desert regions and semi-arid regions devoid of vegetation, there is practically no obstacle to arrest the forward movement of wind excepting by some infrequent rock masses or buildings on coastal regions. When they meet with an obstacle the forward movement of wind is stopped and the load is deposited at the place. Hence these fragments are carried to a great distance. Generally the load is not carried very high.

Deposition—When the forward movement of wind is arrested the sedimentary load is at once deposited. Sometimes this deposition may be a temporary one to be swept away again by the next wind blast but at times they are deposited more or less firmly and get stability for a great length of time. Such wind formed deposits are called *aeolian* deposits after the name of Aeolus, the god of wind. One peculiarity of such aeolian deposits is the sorting action produced upon them as is the case with the water-borne sediments. The rock particles in an aeolian deposit are arranged according to their size and weight. The lighter and finer products are carried farther than the heavier and the larger ones. The finest particles are carried farthest and float for a considerable time in air and then settle anywhere on the continental sectors or oceanic areas.

Loess—It is a special kind of aeolian deposit. This German name has been coined in the geological literature from an Alsatian word meaning fine-grained buff-coloured deposits. Ordinarily loess does not show any horizontal layering but consists of loosely held layers of variable thickness and is traversed by vertical roots of trees giving the deposit a vertical cleavage. This is responsible for the formation of steep scarp-like aspect from such deposits by erosion. This type of deposits is very fertile. Chemically loess consists mostly of clay with microscopic grains of quartz, felspars, mica, calcite etc. Loess also contains, at times the remains of land animals.

Loess is a conspicuous deposit in Northern China. It covers an area of nearly 230,000 square miles there and has thickness of nearly 300 ft. The material has been derived from the Gobi desert and borne by wind. This area is extremely fertile. The yellow colour of the deposits has given the name of the Yellow River and the Yellow Sea of China. Such deposits are easily eroded away as they are very loose (PL—21).

Loess also occurs in Central Europe, U.S.A. and South America. Similar deposits in the Mississippi Valley have been named *adobe*.

Dunes—These are mounds of sand formed by the action of winds. When the surface is irregular, it is called a *sand hill* but when it is in the form of a round hillock or a ridge with a crest it is called a *sand dune*. Sand dunes are prominent features in desert regions and coastal areas. In the coastal areas wind blowing inland produces a belt of sand dunes.

The formation of a sand dune is due to the obstruction to the movement of wind carrying sand particles. This obstruction is generally offered by the irregularities of the surface or by any bush or any building falling on the way of wind. Deposition of the load begins with the slowing down of the velocity of wind which also decreases the transporting power of wind. Once started deposition goes on and as this accumulation grows up, it offers obstruction to the movement of wind. Ultimately there results a round hillock called a sand dune. Such dunes are variable in height, varying from 100 to 300 ft. or more, depending upon the availability of rock particles and the velocity (and hence the transporting power) of wind. Desert regions are conspicuously dotted with such dunes. From one-third to one-fifth of the total area of every desert is covered by dunes.

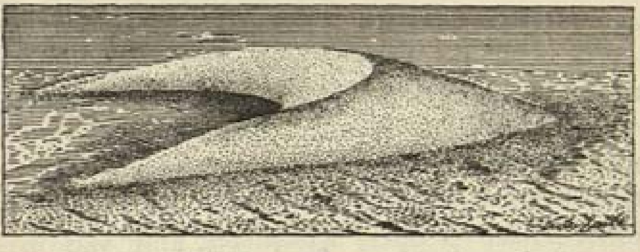
In structure a dune has a gentle slope towards the wind-ward side and a steep side towards the lee side. The lee side is also called a *slip face*. Sand particles are swept on the wind-ward slope. They fall over the crest and come to rest on the lee-ward slope at some angle which is greater than the angle of the wind-ward slope. On the lee-ward side the sand grains rest at an angle which is called the *angle of repose*. This angle varies from 20° to 40° depending upon the coarseness of the particles. The coarser ones will rest at greater angles of repose. The wind-ward slope shows gentle ripple marks. Another feature in the structure of sand dunes is the cross-bedding in the layers. This is produced by the irregular deposition on the eroded surfaces of the dunes, the erosion being caused by subsequent powerful wind gusts.

A dune often moves forward from one place to another in a desert region. This is effected by the lifting of sand grains from the wind-ward slope and adding these on the lee-ward side. The movement is stopped when a shrubby cover firmly binds the sand particles so as not to allow them to be lifted.

Close formation of sand dunes in a region produces an irregular surface. In the depressed areas water often collects specially after heavy showers of rain and forms temporary lakes. In more arid regions however these depressed areas form *oases*.

Two distinct types of dunes are found in desert regions. They are—(a) *barchan* and (b) *longitudinal dune*.

(a) *Barchan* is a crescent-shaped dune with two tapering arms. Their formation is due to the deposition, while moving forward, along the two flanks and consequent prolongation of these flanks into stretched arms. The word barchan has come from a Turkish word.



Fig—1
Barchan

(b) *Longitudinal dunes* are linear accumulations in ridge-like forms of sand particles. These ridges often occur in parallel groups and show toothed summits. These are called *seifs* in the Sahara desert.

CHAPTER X

GLACIERS AND GLACIATION

Glaciers are river-like masses of ice which flow down-hill under the action of gravity.

Avalanches are masses of ice flowing down-hill with great rapidity. As a result of the terrific speed avalanches produce considerable gusts of wind. Avalanches bring materials like rocks, soils etc. from higher to lower levels.

Formation of Glaciers—The distribution of snow is controlled by latitude and altitude. At high latitudes and high altitudes snow is abundant. The lowest line of perpetual snow is called the *snow line*. This in the case of the Himalayan glaciers is 15,000 ft. nearly in the eastern part whereas it is 17,000 to 19,000 ft. in the western part. Except in Australia snow fields or catchment basins of snow are to be found in all parts of the world. The snow when it first falls is in the form of cotton. Successive snow falls press the lower snow and as a result air is squeezed out. The snow after being subjected to considerable pressure assumes a flaky structure. More pressure exercised by successively piled up snow, changes the snow flakes into granular masses under the influence of moisture. These granular masses of ice are called *ne've'* in French and *firn* in German language. Bubbles of air due to the expulsion of air through the melt water and its subsequent refreezing are abundant in ne've'. This ne've' is intermediate in character between snow on the one hand and compact ice on the other. As snow continues to fall and gather, the thickness of the snow field increases and this causes more pressure upon the lower layers of snow. The air in the ne've' is then squeezed out and the ne've' turn to be compact ice. The ne've' is opaque due to the presence of air bubbles though individually the granules of ice are clear. Ice is also clear but layering is a very conspicuous feature in it. The layering may be caused by the successive snow falls or due to the presence of dust particles. Sometimes the clear, compact ice shows blue bands. The snow-field is, at a time, composed of compact ice at the base, ne've' in the middle and unconsolidated snow at the top.

Movement of Glaciers—In mountain slopes such masses of ice, ne've' and snow ultimately begin to flow down-hill under the action of gravity. The movement starts when the weight of the mass becomes more than the retarding friction along the slopes and is also dependent on the temperature. The moving mass of ice is a glacier. *Glacieret* is a term which denotes an intermediate mass of ice between a moving glacier and a non-flowing snow field.

The movement of a glacier is serpentine and conforming to the trends of the valley in which it flows. Ice thus behaves as a viscous mass. There is no wonder in it because though ice is a crystalline solid (hexagonal), it can be made to flow by the application of sufficient force. This force comes from the overlying mass of ne've' and snow. As a rule glacier ice consists of two parts—one moving below which is viscous due to pressure and other upper part which is solidified and is carried by the flowing lower mass. We thus find that cracks or *crevasses,* as they are called, exist in the upper part of glaciers.

The movement is greater in the central part than at the sides. This is due to the fact that the central region experiences friction only from the ground below but on the lateral regions there is friction both from the sides as well as from the base. The terminal deposits thus present a convex form towards the outward and down-hill side.

The lowest limit of glacier movement is dependent on temperature mainly. Glacier retreats or thins out by the melting of snow. Normally the flow of a glacier is maintained by the accumulation of snow in the catchment area. Whatever portion of ice is melted and evaporated is replenished by the supply from the snow field. There are, therefore, two opposing factors in the glacier movement—(i) the supply of snow and consequent pressure from up-hill region and (ii) melting of ice tending to cause shrinkage in the volume of the glacier and its consequent retreat. The snout or the front portion of a glacier moves on below the snow line until the melting and evaporation gain the upper hand and stop the movement. The temperature rise is not the only factor in the forward movement of a glacier. It also depends upon the volume and velocity of a glacier. If the volume be large and the velocity be considerable, wastage can not check the forward movement of a glacier. Generally in the warmer months a glacier shrinks and in moist months it advances. Glaciers near the seas sometimes reach sea water. Parts of it break there and float on the sea water. Such floating ice hills are called *icebergs*. They form danger to navigation. The famous Titanic was wrecked by the collision with an iceberg.

The lowest limit of the Himalayan glaciers is not the same throughout the Himalayan region. In the eastern part, in Sikkim, they descend to as low a level as 13,000 ft. In the western part, in Kashmir, they descend to as much as 8000 ft.

The movement of a glacier varies from a fraction of an inch to more than 100 ft. per day occasionally. In the case of the Himalayan glaciers the movement varies from 1 inch to 3 ft. nearly per day. The daily movement, according to the Italian Expedition in 1909, of the Baltoro glacier in the Karakoram is 5 ft. 10 inches and that of Fedchenko in the Trans-Alai Range of the Pamir Plateau is 1½ ft.

Excepting the occasional temporary advance, most of the glaciers are generally retreating at the present time. They were numerous and advancing in Pleistocene time. The retreat is due mainly to the melting of ice. The product of melting, the melt water, gives rise to englacial and subglacial streams also feeds other rivers. The Himalayan rivers are to a large extent fed by glacial water.

Crevasses—These are cracks of variable breadth and depth on the upper surface of a glacier. These cracks testify to the crystalline and solid nature of the glacier ice, at least on the upper part, and are formed where a glacier bends low over and inclined surface. Where the glacier mass takes motion, a crack is formed running parallel to the rocky wall behind. To this crack the German name *bergschrund* has been given. Crevasses are of several types according to the position at which they are formed.

(1) *Longitudinal crevasses*—These are parallel to the length of the glacier and are formed where a glacier mass emerges from a narrow valley to a wider valley. The availability in space causes the glacier to expand side-ways and longitudinal cracks are formed.

(2) *Transverse crevasses*—These run transverse to the length of the glacier or are parallel to the breadth of the glacier mass. They are caused by slight increase in the inclination of a mountain slope. These crevasses are convex downward owing to greater movement of the central region of the glacier mass.

(3) *Marginal crevasses*—These are cracks formed along the valley sides pointing to up-hill direction. They are also the result of greater movement of the central region of a glacier mass.

Crevasses are likely to be filled up later. They are often covered by dangerous ice bridges which may collapse with slight weight.

Types of Glaciers—Depending upon their structure and location glaciers are classified into three classes—(i) valley glaciers, (ii) piedmont glacier and (iii) ice sheet.

(i) *Valley glaciers*—These are also called *mountain glaciers* or *Alpine glaciers*. Glaciers that flow down a valley like a river are called valley glaciers. They are confined by the valley walls, conform to the valley trends and do not outflank them. They are the commonest type of glaciers. There are about 2000 of them in the Alps. The Hubbard Glacier in Alaska is the longest valley glacier in the world with a length of 80 miles. The Himalayan glaciers are mostly of this type. Indian glaciers are those of the Punjab, Kumaon and Nepal Himalayas such as the Rimo of the Punjab Himalayas (length 25 miles). Gangotri (length 15 miles), Milam (length 10 miles), Kedarnath (length 9 miles) of the Kumaon Himalayas and Zemu (length 16 miles and 650 ft. thick) of the Nepal Himalayas. Most of the Himalayan glaciers are small being of 2 to 4 miles in length. Larger glaciers are however met further north in the Karakoram Range, the noted ones of which are the Biafo (37 miles long) and Baltoro (36 miles long and 400 ft. thick) falling into the Shigar tributary of the Indus, and the Hispar Glacier (38 miles long) and the Batura (36 miles long) flowing between the Hunza Valley and the Siachan (45 miles long) falling into the Nubra tributary of the Indus. The Fedchenko in the Trans-Alai Range of the Pamir region is 48 miles long and 1800 ft. deep. It is however outside the proper Himalayan region.

Glaciers occupying hanging valleys are called hanging glaciers. They are distinct from the main valley glaciers and do not meet the main glaciers at the same level. Some of the Himalayan glaciers are of this type especially those of Sikkim and Kashmir.

(ii) *Piedmont glaciers*—These glaciers are intermediate in form as well as origin between the valley glaciers on the one hand and ice sheet on the other. This is a type of glacier formed at the foot of mountains. When two or more valley glaciers come out of the valley and fall to the plain they unite to form a bigger ice mass which is called a piedmont glacier. Noted examples are Malaspina Glacier and the Bering Glacier in Alaska.

(iii) *Ice sheets*—These are huge covers of ice, enormous in size and thickness, that rise high above the mountain peaks and completely bury them. At present Greenland and Antarctica only present examples of this type. Smaller ice sheets are called ice caps or plateau glaciers and are found in Iceland. Ice sheets generally discharge into the seas their masses of ice as icebergs. Towards the marginal part and near the sea, where the thickness is less, high mountain peaks stand up as islands in oceans. The island-like projections are called *nunataks*.

Geological Work of Glaciers—This consists of three distinct processes of erosion, transport and deposition. Together these processes are included in the term glaciation. Distinct features are associated with each of them which are discussed below.

Erosion—The erosive action of glacier is affected by abrasion and is aided by frost-action. In regions above the snow line frost wedging is an important factor of erosion. The region which encloses a snow field, shows an amphitheatre-like basin and is surrounded by steep-sided blunt headed peaks which are called *cirques or corries*. The area enclosed by cirques gathers snow and nourishes glaciers which move outward and downward. The cirques show extremely rugged topography. They are the result of the process called *nivation*. Nivation consists of quarrying of rocks mostly by frost action. During day time or in summer days, with the rise of temperature, some snow will melt and the melt water will percolate through the joints of the rocks. During night time the water will freeze and with consequent increase in volume, the rocks will experience a shattering effect. As a result of this part of the rocks are quarried and the debris is plucked and carried away by avalanches or by the melt water flowing downward or by glaciers. Nivation is concentrated at the flanks and the under-side of a glacier. The result is the scooping of a hollow. As the process continues the sides of the valleys are undercut and become steeper and irregular. In course of time the peaks turn to by cirques. These cirques recede with progressive erosion and the glacier basin is enlarged thereby. When the glaciers vanish by melting as a result of the rise of temperature, the hollows turn to be lakes. Where two cirques meet at an angle the dividing ridge between them is called an *arete*, and three or more cirques unite and after erosion form turreted masses called *horns*.

Strictly speaking nivation is not a glacial action though it is intimately associated with it. True glacial erosion starts with the movement of glaciers. This consists of mechanical quarrying and abrasion by glaciers, aided, no doubt, by frost.

action. The erosion by glaciers depends upon several factors among which the following are important.

(i) *The thickness of the glacier ice*—It is a very important factor in glacial erosion. The more the thickness, the more the glacial erosion. The thinner parts of glaciers perform less erosion and sometimes pass over the bed rock without doing any erosion.

(ii) *Amount of rock material carried by the glacier* —The products of erosion, particularly of frost action, fall on the glacier mass and are carried away. Sometimes the rock debris reaches the bottom through the crevasses. Rock fragments also are torn away by glaciers from the bed rock by plucking. Glaciers exercise firm grip upon rock fragments. While moving over the bed rock, the rock fragments effectively grind the floor, wearing them constantly. The firmness exercised by glaciers on the stones is a factor in glacial erosion. Where the grip of the glacier is loose, the erosion is not pronounced, as in melting ice, but where the grip is firm abrasion is done effectively. The sides of the valleys also are worn away and the debris is added to the glacial *drift*, which is the entire mass of products carried by glaciers. As a result of the erosion the bed rock is smoothed, polishsd, rounded, striated and grooved. The striae or the linings produced by glacial abrasion are very conspicuous in the valleys occupied by glaciers. These striae points to the direction of flow of the glaciers. If the initial bed rock be hummocky the small hillocks are abraded and low and rounded mounds are formed which are called *roches moutonnees*. These may also result from hard parts of bed rocks while the surroundidg weaker rock mass may be eroded away easily. The

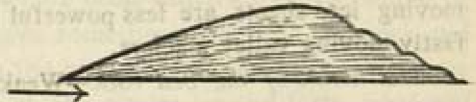


Fig.—32
Roches moutonnees

up-hill side, (from which the glacier descends) is gently sloping and is called the *stoss side* while the down-hill side is steep and is called the *lee side*. Sometimes very hard rocks, like volcanic plugs, offer great resistance to the ice flow and stand as pillars in the glaciated valleys. These structures are called *crags* and the lee side, which is sloping in this case, is called the tail. This structure is just opposite to that of roches moutonnees.

Not only the bed rock is abraded smooth but also the sides of the valleys occupied by glaciers. The valleys occupied by glaciers are U-shaped instead of being V-shaped as in the case with the valleys occupied by rivers. The stream-formed spurs are also eroded away. As glacier ice conforms to the valley trends, length-wise the valleys occupied by glaciers are serpentine.

In the process of abrasion the rock fragments are also worn away. They develop conspicuous facets which are smooth and striated. The finer products of erosion, the rock flour, both from the bed rock and from the abrading fragments are carried away by melt water.

The tributary valleys, in the case of glacier-occupied ones, are not at the same height as the main valleys. This is because of the fact that the glacier ice is thicker in the main valleys than in the tributary valleys. The main valleys are therefore eroded away more rapidly while the tributary valleys are eroded less rapidly. The result is that the tributary valleys are left hanging above the main valleys. After the disappearance of glaciers these hanging valleys form water-falls.

(iii) *The velocity of glaciers*—The greater the velocity of the glaciers, the more is the erosion. Roughly the abrasive power varies as the cube of the velocity of the glacier. Steeply inclined surfaces thus help speedy glaciation. Slowly moving ice sheets are less powerful eroding agents than the fastly moving valley glaciers.

The nature of the bed rock—Weak bed rocks are easily eroded away whereas hard bed rocks take considerable time to be eroded away. The hard rocks on the way offer great resistances to the glacier movement and form crags. On the bed rock itself the effect ts conspicuous. Where the bed rock is weaker, erosion is more pronounced than where the be d rock is hard. This differential erosion at times produces a step-like aspect in the glaciated valleys. This step-like feature is called the *glacial stair way*. They may also result from the quarrying of vertically jointed rocks.

One peculiarity of glacial erosion is that glaciers can erode the valleys below the sea level. The down-cutting by rivers stop at the sea level but glaciers can deepen their valleys below the sea level. This is known as over-deepening by glaciers. In the sea coasts this produces characteristic glaciated deep submerged valleys which are known as *Fjords* (or *Fiords*). Originally the valleys near the coast was eroded below the sea level by over-deepening. Afterwards either by the rise of the sea level or by the sinking of the land mass which may be the effect or isostatic readjustment following Pleistocene deglaciation, the sea water invaded the coast and these valleys formed inlets of seas. They are abundant in high latitudes.

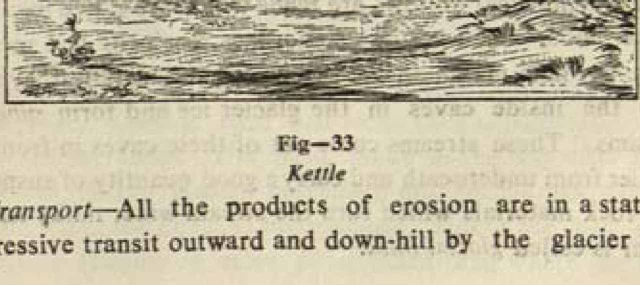
Melting of ice and related features—There are some features which are the direct outcome of melting of glacier snow. They may be considered here though their origin is not wholly due to erosion.

As already pointed out the rise of temperature causes melting and evaporation throughout the entire surface of a glacier. This is specially pronounced in summer days. The product is the melt water. Where the slope is favourable this melt water forms streams and glacier supports them on its upper surface. Where the slope is opposing it forms lakes. Such streams generally fall into the surface fissures (the crevasses) and by the whirling action of stones carried by such rivers, cylindrical hollows are made which are called *moulins* or *glacier mills*. Such hollows sometimes reach the bed rock and leave pot hole marks on the bed rock but generally they merge into the inside caves in the glacier ice and form *subglacial* streams. These streams come out of these caves in front of a glacier from underneath and carry a good quantity of suspended fine rock materials which turn the stream water milky and this water is called *glacial milk*.

Streams occuring in the glacier body itself are known as *englacial streams.* Streams supported on the upper part of a glacier are called *superglacial streams.* These are frequent along the lateral margins of glacier valleys. Streams occuring at or near the bottom of a glacier are called *subglacial streams* The terms subglacial, englacial and superglacial also refer to the rock materials carried by glaciers with the same meaning.

The dust particles on the surface of a glacier are likely to absorb more of solar heat in comparison to surrounding regions of snow. Hence this dusty patch will melt the snow beneath it and small basins will be formed. These basins are called *dust wells.* But if the thickness of the rock fragments be considerable, the reverse will be the case. The rock material will serve as an insulating cap and prevent the snow below from melting. Sometimes huge blocks are seen standing on a pedestal of snow whose origin can be explained by the above process. These blocks are known as *glacier tables.*

Kettles—These are basin-like hollows made in the out-wash plains or other type of glacial deposits. Their diameters range from a few yards to a few miles. Commonly they contain water. These depressions are the result of melting of ice either wholly or partially buried under glacial drift and consequent collapse of the upper part.



Fig—33
Kettle

Transport—All the products of erosion are in a state of progressive transit outward and down-hill by the glacier ice.

A huge quantity of rock debris is carried by glaciers on their upper surface, which is called the glacial drift. This rock debris comes from the valley sides. Avalanches also contribute to the rock debris. By the process of plucking some rock material is picked up from the bed rock. Regelation i.e. melting under pressure and subsequent freezing, is a very important process in this respect. The materials are arranged along the sides, under the glacier and notably at the terminus. All the rock materials tend to accumulate at the terminus. From the terminus melt water in the different types of glacial streams carries the rock material to the seas or lakes. Glaciers themselves, in coastal regions, carry their rock debris to the seas.

Deposition by Glaciers and Associated Features :

One of the peculiarities of glacial deposits is the unassortment of these deposits. In glacial deposits big boulders and finest rock materials are all dumped at a place. In this respect glacial deposits are unlike the river and wind-formed deposits. In the river and wind-formed deposits, the sediments are arranged according to their size and weight, so that the big and heavy blocks occur near their places of origin and the finer sediments are carried further away. Glacial deposits are wanting in this arrangement. The unassorted glacial drift consisting of rock materials ranging in size from boulders to the finest rock flour is known as *till*. The rock formed from till is called *tillite*. When, however, snow melts, glacial streams are formed and then the combined effects of water and ice are noticeable upon the sediments so that they become partly or wholly sorted, washed and stratified. Drift of this nature is called the stratified drift. The facetted and striated stones in them betray their glacial origin.

The big boulders which are carried by glaciers are known as *erratics* (PL—23). They are huge in dimension. Some of these are deposited in unstable elevated positions and are known as *perched blocks* (*roches perchees*). At times they are delicately balanced upon the glaciated bed rock. These are then known as *pocking stones or logging stones*. Their dissimilarity in rock composition with the rocks below points to their transport to the place.

Types of moraines :—

Most conspicuous of the glacial deposits are the different types of *moraines* which have received different names according to the place of formation in glaciated valleys. They are :—

(1) *Ground moraines*—The moraines (or drift) which are deposited upon the ground or the bed rock upon which a glacier is moving are known as ground moraines. In thickness they are thin and their surface is irregular due to uneven deposition of rock materials carried by the glacier because whatever load of rock debris the glacier can not carry, is deposited on the bed rock over which the glacier flows and this results in uneven deposition.

(2) *Lateral moraines*—These are the moraines which are deposited along the margins of the glaciated valleys and are ridge-like accumulations of rock debris which are sometimes 100 ft. or more in height. The lateral moraines often persist for sometimes even after the disappearance of the glacier.

(3) *Medial moraines*—These are also ridge-like accumulations of rock debris formed along the middle part of a glacier. They originate by the union of two lateral moraines of two intersecting valleys. They are transitory in existence and are easily removed away because of their central position.

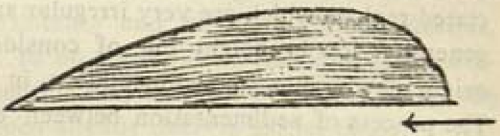
(4) *End moraines or Terminal moraines*—These are accumulations of rock debris at the end of terminus of a glacier. Their height is sometimes 100 ft. nearly but they are of a very small width. Their length is determined by the width of valley floor. They present a convex side downward which is due to faster movement along the central part of a glacier.

There are two more types of moraines, one is the *englacial moraine* and the other is the *subglacial moraine.* They denote only masses in drift but no depositional features.

The rock debris that is enclosed by a glacier mass is called an *englacial moraine.* The dust particles between successive snow falls which make layering conspicuous in the compact ice and the part of rock debris buried on the upper surface of a glacier which falls into the crevasses and sinks below form the englacial moraine.

The moraine that occurs near the sole of a glacier is called the *subglacial moraine*. The part of the rock debris which reaches the bottom through the crevasses and the rock material that is plucked on the way, constitutes the subglacial moraine.

Drumlins—In glaciated regions, the ground moraines consist of low mounds of clay which sometimes, contain cores of bed rock. These small hillocks are of the shape of inverted tea-spoons. Drumlins have their long axes parallel to the direction of ice movement. Their up-hill sides are blunt and the down-hill sides are smooth and gently sloping. They thus show features which are just opposite to those of roches moutonnees. They are sometimes one mile or more in length and nearly 200 ft. in height.



Fig—34
Drumlin

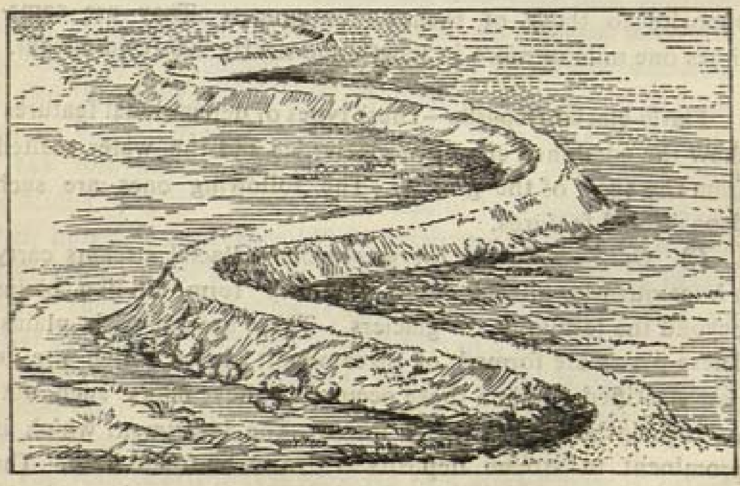
Fluvio-glacial Deposits—These types of depositional features show the combined effects of glacier ice and the water melted from the snow of the glacier. The following ones are such depositional features.

(i) *Outwash plain or overwash plain*—Glacial streams carry a huge quantity of rock debris and they form fan-like plains beyond the terminus of glaciers. These are out-wash plains. These plains are formed of stream-built drifts which are in part stratified. When these occur on valley floors such outwash plains are called *valley trains*. The assortment which is prominent in stream deposits is also to be found here. The coarser sediments are deposited near the terminus of the glacier while the finer sediments are carried further down-hill.

Some outwash plains are marked with kettles and show irregular surfaces. These are called pitted outwash plains.

(ii) *Kames or kame terraces*—Regions covered with glacial drift often present more or less flat-topped, steep-sided and irregular elevations which are called kames or kame terraces. These hillocks are built of stream-borne deposits and hence show rude stratification. Their origin is believed to be due to the pouring of sediments by glacial streams from a high level or sedimentation between the valley walls and the tongue of a glacier.

(iii) *Eskers*—These are winding steep-sided ridge-like features built of stream-borne drift. This word has been derived from an Irish word meaning a path. This refers to the fact that such ridges are the only means of communication in glaciated regions which are very irregular and swampy. They are generally low in height but of considerable length. Their origin may be due to sedimentation in a subglacial tunnel. The process of sedimentation between confined valley walls referred to in the origin of kame terraces, may also produce these ridges.



Fig—35
Esker

(iv) *Crevasse fillings*—These are short ridges generally straight and are formed by filling up of crevasses by stream-borne rock debris.

(v) *Varves*—These are layered clays alternating with coarser and finer sediments. In summer and rainy seasons snow melts and water carries a good amount of sediments. The summer and rainy season sediments are coarser and the winter sediments, which are deposited in calm water are finer. These two layers of deposits therefore mark annual deposition in lakes in glaciated regions. The same episode is repeated every year so long as the lakes persist. By counting such pairs, the age of the sedimentary beds can be roughly determined.

Indicators of Glacial Action and Climate—The features related to the glacial erosion, melting, transport and deposition indicate the existence and work of former glaciers, although there may be no glacier ice at the time of observation. Among these mention may be made of the following, the origin of which has been already dealt in earlier pages.

(1) *Scratched, grooved and facetted rock fragments.*

(2) *Smooth and scratched bed rock.*

(3) *U-shaped valleys.*

(4) *Hanging valleys*—Though these may also result from rapid erosion of the main valleys by rivers.

(5) *Cirques.*

(6) *Features associated with glaciation*—Like the different types of moraines, drumlins, eskers, kames, out-wash plains and kettles.

(7) *Unassorted deposit and tillite.*

(8) *Undecomposed felspar in the drift*—In humid temperate climate the felspars change to clay but in glacial and arid climates it remains undecomposed. So it is not only suggestive of glacial climate but also of arid climate.

(9) *Absence of red ferruginous and black carbonaceous matter of the drift*—The red deposits indicate arid climate and the black carbonaceous deposits indicate temperate humid climate. So their absence indicates glacial climate.

Glacial Climates in India—Glacial climates are not rare in the geological history of India though they are infrequent. The earliest evidence of glacial action is obtained from the scratched pebbles of the Kaldrug conglomerate in South India and a Dharwar (Huronian) age has been assigned to it by R.B. Foote who examined the area.

From the rock exposures at Bap and Pokran areas in Rajasthan and Chattarpur area of Madhya Pradesh evidences of two quick and successive glaciations in the Vindhyan period have been suspected. Examination of rocks of Sidhi area of Madhya Pradesh goes to support a glaciation even in Cuddapah period (of Bijawar age).

Next evidence of glacial action is obtained from the Talchir rocks of Orissa of the Lower Gondwana (Up. Carboniferous) age. The component rocks are green laminated shales and fine sandstone, underlain by the Talchir boulder bed. The glacial action is indicated by the presence of undecomposed felspars in the sandstone, green colouring matter in the shales, and the striations and facets on the boulders. The boulder betrays a glacial climate at that period. The age of the boulder bed has been determined to be Uralian or Up. Carboniferous. This boulder bed is wide in distribution and occurs in such areas as Hazara, Simla, Salt Range (in West Pakistan), Rajasthan, Madhya Pradesh and Orissa. This is suggestive of the presence of an ice sheet in India at that time. In the Panchet beds of the upper part of the Lower Gondwana System of rocks another glacial action may be detected from the presence of undecomposed felspars in the sandstone. This is however, not so widespread as the former one. The age of the Panchet bed is Triassic. Glacial climate in Panchet time is not certain as the presence of undecomposed felspars may also indicate arid climate.

The most recent glacial climate in India occurred in the Pleistocene time. The glacial climate was more or less worldwide for the evidences of it are abundant in America and

Europe as well. Glaciers are thought to have covered the Extra-Peninsular India, but in the Peninsular part the climate was rather cold. In the Peninsular India, the evidences for this mild climate are to be sought in the effects upon the distribution of the Himalayan plants and mammals whereas in the Extra-Peninsular or Himalayan region nearly all the indicators of glacial action are present and the extinction of the Siwalik mammals also points to the same evidence. There was not an uninterrupted glacial climate in Extra-Peninsular India during the whole of the Pleistocene period. On the other hand evidences indicate that the period was marked by several warm climates intervening the cold glacial climate. In the opinion of experts there were four periods of glacial climates at that time separated by three warm inter-glacial periods.

Causes of Glacial Action—The climate of a particular area is controlled mainly by the solar radiation of heat but terrestrial factors such as latitude, altitude, ocean currrents, drift of wind, rain-fall, distance from the sea and the nature of the soil also exercise a good deal of influence. In a temperate equable climate the earth receives just the necessary amount of solar heat and it is also distributed uniformly. The more the radiation of heat from the earth's surface can be retarded the more warm will be the climate. Glacial climates are therefore explainable by either a less amount of solar heat or by an uneven distribution of it on the earth's surface. As the above mentioned factors are operating from the earliest time, the glacial climates may be the result of long continued astronomical and terrestrial factors, among which the following important ones can be mentioned briefly.

Terrestrial Factors :—

(i) *Elevation of the continental masses*—It is an observed fact that at higher altitudes the temperature is low. A fall of 1 C is noticed for every 540 ft. of altitude. This is due to the fact that the upper air is rarefied as well as without any dust particles. The cold air blowing over the snow-field lowers the temperature of the surrounding areas. The surface of a snow-field also reflects a great amount of solar heat. This will increase the size of the snow-field and the possibility of a glacial climate is greatly enchanced. It has been observed that an initial lowering of temperature by 1° C below the freezing point is capable of the final lowering of the temperature by 20° C. Moisture-laden clouds retard the radiation of heat from the earth's surface and hence cause the climate to be warm. This warming effect of the clouds is at its maximum over low lands and minimum at high altitudes. The presence of mountain masses causes rising of warm air and sinking of cold air. This affects the retardation of heat and as a consequence a lowering of temperature is effected. Then again during a glaciation period such as that of Pleistocene, a great amount of oceanic water will be locked up on the land in the form of snow and ice. This will cause a lowering of the sea level and an elevation of the continental mass. Warm sea currents are likely to be affected by the land bridges that will come into existence after the pronounced upheaval of the continental masses or lowering of the sea level. This will have a marked effect in the lowering of temperature.

An upheaval of a mountain mass is also capable of modifying the climate of a particular area by causing a general lowering of temperature by preventing the equatorial warm air from moving towards high latitude. Generally lower temperature effects are noticeable at mountain-building times. The early Proterzoic, Permian and Pleistocene glaciations were marked respectively by the Lauratian, the Appalachian and the Cascadian and the Himalayan upheavals. Uplifts of mountains may explain the sudden appearance of glacial climate but it fails to explain the rather prolonged interglacial warm climates as the elevation will continue to exist unless and until reduced by erosion or lowered by diastrophic movements. The evolution of the Rocky Mountains was not attended with glacial climate.

(2) *Polar wandering*—The wandering of poles and the shift-

ing of the earth's axis at different periods of the earth's history have been evoked at times to account for the glacial climate of a particular area, but apart from slight shifting, a change in the position of the earth's axis is dynamically impossible since the earth is as rigid as steel. The idea of continental drift carries with it a corollary of the wandering of poles to account for the variations of climate in the past but there should be some limitations to this idea of polar wandering though there is possibility of wandering of parts of the continents.

Atmospheric Factors :—

(3) *Variation in the amount of carbon dioxide in the atmosphere*—The greater the amount of carbon dioxide in the atmosphere, the more the increase in temperature and the less the amount of carbon dioxide the more the decrease in temperature, because carbon dioxide can absorb a little amount of heat. There is however no direct evidence to this assumption.

(4) *Variation in the amount of volcanic dust*—A cloud of volcanic dust will prevent the solar heat to reach the earth's surface by reflecting the solar heat. Therefore it is held that increased volcanic activity resulting in greater amount of volcanic dust in the atmosphere will cause a lowering of temperature.

(5) *Variation in the amount of moisture in the atmosphere*—The more the amount of moisture in the atmosphere, the more the increase in temperature. This is beacuse moisture laden clouds prevent radiation of heat from the surface of the earth, thus causing an increase in temperature.

The atmospheric factors produce by themselves very little effect upon the climate.

Astronomical Factors :—

(6) *Variation in the eccentricity of the earth's orbit*—The eccentricity of the orbit of the earth is variable at times. The orbit sometimes approaches a circle and sometimes a long

ellipse. Then again during the winter season of the southern hemisphere the earth is at its greatest distance from the sun i.e. at its aphelion, while during the time of summer season of the same hemisphere, the earth is at the nearest distance from the sun i.e. at its perihelion. During the period of greater eccentricity of the earth's orbit, the hemisphere in which there is winter season in aphelion will experience a longer and more severe freezing temperature thus initiating a glacial climate.

(7) *Change in the inclination of the earth's axis to the plane of the orbit*—These two are periodic factors and demand glaciation at regular intervals but records of glacial climates do not furnish any such regular periods of glaciation at intervals.

(8) *Variation in the amount of solar radiation of heat*—Solar radiation of heat varies through certain degrees. Larger variations are able to produce greater climatic changes.

(9) *Sun spot activity*—The variations in the amount of heat is greatly influenced by sun spot activity. During periods of increased sun spot activity, the solar radiation is greatly increased. This will not cause an increase in temperature but wili tend to lower the temperature as storms are frequent during the period of increased sun spot activity thereby radiating heat to a greater extent. Therefore according to Hutington increased sun spot activity will lower temperature and may initiate a glacial climate.

CHAPTER XI

LAKES

Lakes are bodies of water, either fresh or saline, in natural depressions on the surface of the earth. They range in size from a pond to the largest Lake Superior (fresh water) and the Caspian sea (saline). They abound in glaçiated regions. Some lakes are fed by rivers, others have no outlets. They are important as modifier of local climate and act as reservoirs to surplus water in streams and thus prevent the occurrence of floods. They are deposition grounds of water borne sediments and in some favourable places peat beds and bog iron ores are formed in them. They may thus be the sites of future iron ore deposits (c.f. Lake Superior iron deposits) and coal seams (c.f. some of the Gondwana coal fields) in some cases.

Formation of Lakes—Formation of lake basins due to diverse causes is in operation from the earliest time. The ancient lakes were extinguished as a result of sedimentation, crustal deformation, drainage by streams etc. The recent ones are surviving but are also liable to meet the same fate. These basins after catching water turn to be lakes. Lake basins may originate in any one of the following ways.

(1) Lakes formed by crustal movements— Basins may be formed by either faulting or folding. Due to faulting a hollow may be formed, and both faulting and folding may tilt a river valley so as to block the river to form a lake. The Pleistocene lakes of Kashmir, some of the Kumaon lakes. Lake Geneva and Lake Constance in Switzerland are examples.

(2) Some basins are the result of earthquakes as for example some of the Alpine lakes.

(3) Basins may be formed by meandering rivers. They are called ox-bow, horse-shoe or cut-off lakes. The recent Kashmir lakes are examples.

(4) Tributary river by forming a bar of sediments across the main river may block it to form lakes. Pangkong lake in Kashmir is an example.

(5) Some lakes are formed in the flood plains of rivers. As for example Lake Maurepas in the U.S.A.

(6) Rivers may form lake basins by erosion at the foot of a hill as a result of the impact of the water-fall. It may also form lakes in pot holes formed by the whirling action of stones carried in river eddies. The lakes generally come into existence after the water falls or rivers have died away.

(7) Lakes may be found to occur in depressed areas in dried up river beds as for example, the *bills* of the Ganges delta and the Manchar lake in Sind.

(8) Volcanic basins—Lakes may be formed in the crater of a volcano. The Lonar lake in the Buldana area of Bombay is an example. At times lava flows may block a river by flowipg across the river valley.

(9) Rock-fall or land-slide basins—A river may be blocked by a land slide across its valley. The Bundelkhand lakes and the Gohana lake in Garhwal are examples. The last one was formed by a land slide across a tributary to the Ganges in 1893.

(10) Solution basins—Basins are sometimes formed in sinks produced by the solution of rocks like limestone and rock salt from underneath. If the outlets of the basins be clogged with impermeable rocks, these sinks turn to be lakes. The Salt Range lakes are of this nature.

(11) Basins formed by marine action—In coastal regions sea waves sometimes build bars or spits across the coast or the mouth of a river thus converting the back water into small lagoons, which are small lakes formed in coastal regions. The Kayals of Kerala, the Pulicut lake in Madras, the Chilka in Orissa are examples of this type of lakes.

The Caspian Sea, the world's largest saline lake, was once a part of the sea and then cut off.

(12) Wind-formed basins—Basins are found in the sand dunes. The dhands or the alkaline lakes of Sind and Western Rajasthan are of this origin. Basins are also produced by wind deflation i.e. blowing away of fine particles from the surface. As these wind formed basins occur mostly in desert regions

they seldom contain any lake excepting after occasional heavy showers of rain.

(13) Glacial basins—Majority of the lakes owe their origin to glaciers. Lake basins are formed by glacial erosion by scooping of bed rocks. The Pir Panjal lakes are of this nature. Sometimes river courses are blocked by piling up of morainic matter across their valleys causing the formation of lakes. Some of the Kumaon lakes are of this nature.

Indian Lakes—Lakes are of little importance to India.

Lakes of Peninsular India—

(1) Coastal lakes—(a) Lake Chilka—It is in the Ganjam district in Orissa. This has been formed by the formation of bars or spits built by sea waves close to the coast thus converting the enclosed water into a lagoon.

(b) Pulicut lake—It occurs in the Madras district in Madras Srate. Its origin is similar to that of the Chilka lake.

(c) Kayal—Kayal is a local name in Kerala for a lagoon. Similar lakes occur in the Malabar Coast of India. Their origin is similar to that of the former two.

(2) Lonar lake—It occurs in the Buldana area of Bombay. It has a circular outline with a diameter of nearly one mile and a depth of 300 ft. The water is highly charged with sodium carbonate and sodium chloride which are precipitated in summer days.

According to one view this lake occupies a volcanic crater and according to a second view this has been formed as a result of subsidence of basaltic rocks (the Deccan traps) in a circular outline due to the escape of lava and gases from below. (PL—24).

(3) Sambar lake—This is a shallow lake which occurs in Rajasthan. During monsoon periods its area is 90 square miles and depth is about 4 ft. At other times it is dry. The saline content in Sambar lake (as well as in four other smaller lakes in Rajasthan like Puskar, Debar etc.) is due, according to Holland and Cristie, to the blowing of salts from the Rann of Cutch region by the south-west monsoon blowing over

Rajasthan. They have calculated that nearly 1,30,000 tons of salts are borne annually. This salt is dropped in various parts of Rajasthan and later concentrated to these lake basins by inland drainage. Other causes may be the former connection with the Arabian sea, marine transgression, chemical solution and precipitation in these lake basins.

(4) Dhands—These are the alkaline and saline lakes of Sind (West Pakistan) and Western Rajasthan. They are held to have aeolian origin. They contain carbonate, chloride and sulphate of sodium.

Lakes of Extra-Peninsular India—

(8) Lakes of Tibet—The largest lake in Tibet is the Koko-nor with an area of 1630 square miles. Other noted lakes of Tibet are the Manasorawar (200 square miles in area), Rakas Tal (140 square miles in area) and Gunchu Tso (30 miles to 15 miles in length). The first two are fresh water lakes and last one is saline.

Tibetan lakes have no outlets and receive inland drainage. Hence their water is getting saline every year. They are also getting smaller in area as a result of increasing desiccation. This desiccation is due to the obstruction of the monsoon winds by the Himalayas and absence of rainfall. Borax is an important constituent of the salts of these Tibetan lakes.

Their origin is attributed to blocking of rivers by piling sediments across their valleys either by tributary rivers or by glaciers. Some are due to glacial action formed by scooping out of bed rock. Some are due to the uplift of the streams by crustal disturbances resulting from the Himalayan upheaval.

(2) Lakes of Kashmir—Noted among the lakes of Kashmir are Pangkong, Tsomoriri, Salt Lake, Wular and Dal. The Wular and Dal are fresh water lakes while others are saline. The Pangkong lake in Ladakh is 40 miles long and 2 to 4 miles broad and is situated at an altitude of 14,000 ft. Tsomoriri in Rupsu is 15 miles long, 2 to 5 miles broad and is situated at an altitude of 15,000 ft. The Pangkong, Tsomoriri and the Salt lake owe their origin to the damming up of the main valley by sediments brought by tributary rivers. The

Wular and the Dal basins are thought to be hollows in the alluvium of the Jhelum River. Smaller lakes in Kashmir and neighbouring areas are called *torns*.

(3) Lakes of Kumaon—Noted among these are Naini-Tal, Bhim Tal and Khewan Tal. Their origin is thought to be due to blocking of streams, crustal movements and solution of bed rocks.

Nature of Lacustrine Deposits—Lacustrine or lake deposits present a peculiar feature in which the coarser sediments are deposited near the margin and finer sediments in the central part. Gravel beds are found in the border areas of the lake deposits and fine sandstones and shales are found in the central part. Talchir deposits of Lower Gondwana rocks in Orissa present this peculiarity.

Swamps—These are marshy grounds saturated with water. These abound in four regions—(i) flood plains, (ii) deltaic regions, (iii) recently glaciated areas and (iv) coastal regions. Swamps are important in the fact that in such areas peat is formed. Besides this these areas also supply at times diatomaceous earth which is a kind of mud with siliceous matter, the last being derived from the silica of the shells of minute plants called diatoms. This diatomaceous earth is used in the manufacture of dynamite and as an abrasive. Swamps are also very fertile especially when they are dried. Notable examples are the Dismal Swamps of Virginia and Carolina and the swamps of Sunderban in the Ganges delta in Bengal.

Peat—When fresh peat contains about 80 p.c. of water which may come down to 20 p.c. by air drying. It often contains about 2 p.c. of N_2 which may be converted to ammonia. By moderate pressure peat can be changed to a dark brown mass like lignite. With high pressure and temperature it can be changed to a coal-like substance. According to Bergius peat would be converted into bituminous coal in 8 million years under pressure and in presence of water at 50°F. It visibly contains plant materials only partially changed. At 100°C peat gives the following composition—C = 56—66%, H_2 = 5—9%, O_2 = 18—33%, N_2 = 2%, ash (inorganic salt) = 1—6%. Peat is sometimes used as fuel.

Formation of Peat—Under humid and temperate climatic conditions and in stagnant and shallow water bodies, such as lakes and lagoons, formation of peat generally takes place. In such environment with oxygen, the plant debris cannot be changed to higher ranks of coal. When the plant remains undergo decay humic and ulmic acids are formed. Bacterial activity is mainly responsible for this change. The acids and water containing oxygen destroy the bacteria later and the decay of the plant materials is retarded considerably. Thus slow decomposition of the plant debris takes place and peat is formed at last. It is most abundant between 35—60°N latitudes where the temperature is generally 40 to 60°F.

Depending on heat, pressure, nature of accumulation basins and plant materials many chemical changes take place, when carbon and hydrogen separately combine with oxygen (hydrogen combining more rapidly than carbon). This produces a gradual carbon enrichment as the process continues.

Occurrence of Peat in India—At present peat-like substance is under active formation in the Sunderban area of South Bengal in the Ganges delta and in the Nilgiri Hills in South India. The former is called low level peat because it is formed very near the sea level while the latter is called high level peat because its formation is taking place at an altitude of 6000 ft. Peat is also found at a depth of 20 to 30 ft. below Calcutta intermixed with sand and loam. Examination has revealed the presence of very little moss but abundance of the remains of trees like Heritiera littoralis (Sundri trees), Willows, Cypress, Phragmites, leaves of Ficus cordifolia (fig), seeds and leaves of other trees. The volatile matter is present to the percentage of 50 to 60 and moisture 15 to 20, In the marshy Sunderban area peat is formed from the remains of Sundri trees mostly and also of other types of vegetation. Vegetation here differs from that of the Nilgiri area where Spagnum, Heath, Erica, Scirpus, Carex etc. are the main types of vegetation.

Peat is also found under the Indo-Gangetic Plain at several places.

Bog Iron Ore—Certain valuable iron ore deposits, owe their origin to a result of the activity of certain types of bacteria called iron bacteria and chemical precipitation. These bacteria are very minute organisms which precipitate iron from the solution of iron compounds and oxidise it. One of the soluble compounds of iron is ferrous carbonate ($FeCO_3$), specially in water containing CO_2 (c.f. $CaCO_3$). But there is a limit to the solution and concentration of $FeCO_3$. When that limit is reached, $FeCO_3$ begins to precipitate out. If there be available oxygen it is oxidised and precipitated in the form of Fe_2O_4 and $2\ Fe_2O_3,\ 3\ H_2O$. At the bottom of swamps or lakes where there is not much oxygen, iron is precipitated as $FeCO_3$. How far the process is aided by bacteria and how far it is chemical it is difficult to say.

CHAPTER XII

DIASTROPHISM AND DEFORMATION OF THE EARTH'S CRUST

Movements of major parts of the earth's crust resulting in regional crustal deformations, either in vertical or horizontal or in any inclined direction, are known as *diastrophic movements* and the phenomenon in which such changes are brought about by these movements is known as *diastrophism.*

There are two types of earth movements—(i) *epeirogenic* and (ii)—*orogenic.* The word epeirogenic has come from the Greek words *epeiros* meaning a *continent.* Epeirogenic movements give rise to the elevations and depressions of continents and hence such movements are called continent making movements. Such movements are radial movements of the earth's crust. The rising areas of continents are known as *positive areas* and the sinking areas are known as *negative areas.*

The word orogenic has come from another Greek word *oros* meaning a *mountain.* Orogenic movements give rise to mountains and hence the name. Such movements are tangential to the earth's surface.

Diastrophic movements, comprising the epeirogenic and orogenic types of movements produce displacements which may be in the vertical, inclined or horizontal directions producing elevation or subsidence of an area, folds, faults, or tilting of strata. These movements determine to a large extent the area and elevation of a particular place. The epeirogenic movements are rather sudden compared to the orogenic movements which are very slow. The epeirogenic movements generally accompany some sudden catastrophic changes and phenomena like faulting, earthquakes and the like, and their effects are clear and pronounced in the shore regions.

Epeirogenic movements—Such movements have their effects upon the sea level which is either raised or lowered relative to the land surface. Measurements of elevations and depressions are generally made from the mean sea level which is the mean level between high tide and low tide marks. Changes in position of this sea level relative to the land arecalled *eustatic changes* which produce conspicuous effect on the shore regions. Somewhere the coastal regions are elevated and somewhere these are depressed, Such eustatic changes are due either to the changes in the capacity of the sea-basin or in the volume of sea water of both. The characteristics of a shore line of subsidence have already been stated under the chapter on oceans. It should be remembered that such changes in vertical directions involving relative displacement of land and sea are entirely different from the extension of land into sea by marine construction or extension of the sea towards land by marine destruction. Some notable examples of changes produced by diastrophism will here be discussed.

Examples of Elevation of Land—At present there are more examples of elevation than those of subsidence. This is probably due to the post-glacial changes. An oft-quoted example of elevation is furnished by the Temple of Jupiter at Serapis near Naples in Italy. There are three columns of marble each about 40 ft. high. These columns are bored to a height of 20 ft. from the base by some types of rock boring marine animals like Lithodomus. These testify to the fact that after these columns were built there was a subsidence to at least about 20 ft. when the boring animals bored the columns. Then there was an uplift which elevated the columns again above the sea level. In recent times the area is again subsiding.

Another remarkable example is the elevation of the Island of Palmarola in the Adriatic Ocean. It was elevated 210 ft. nearly in 70 years, from 1822 to 1892 i.e. at the rate of 3 ft. per year.

The shore regions of Norway and Sweden also show clear signs of uplift. This is due to the changes from post-Pleistocene deglaciation.

Indian examples of elevation are furnished by parts of both the east and west coasts of the Peninsular India. Raised beaches, wave cut benches, emerged coral reefs etc. are often seen in several parts of these two coastal regions pointing to the uplift of these areas.

Evidences of inland elvation can not however be so clearly obtained because there is no convenient reference line but extensive surveys will show the effects of elevation and depression in the interior parts of the continents as well.

Examples of Depression of Land—The temple at Serapis, near Naples can also be cited as an example to this point. Drowned river valleys, fiords and submerged forests are features associated with the submergence of a coastal area.

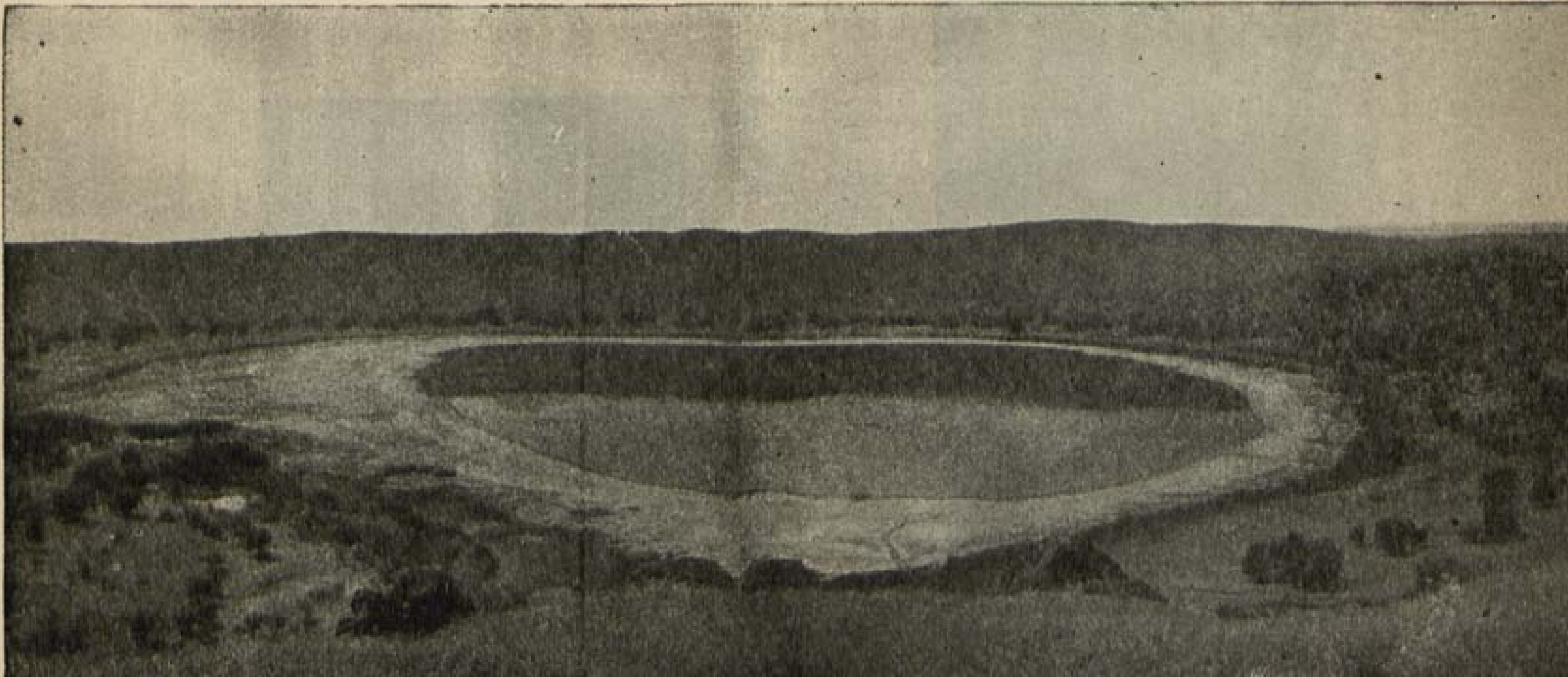
The submerged forests of Bombay and Pondichery coasts are examples of submergence of the coastal region of India. The submerged forest of Bombay is nearly 20 ft. below the mean sea level. The trees occur with their roots in the soil of the submerged area. Peat beds in the Ganges delta are also examples. It should be remembered in the case of the submerged forest that tree trunks may be drifted and being heavier at the bottom due to the roots, will assume a vertical position after settling as is the case in some coal seams. If the roots also extend into the soil as well, then they are examples of submergence of an area.

The causes of these vertical movements are possibly due to isostatic adjustments following glaciation and deglaciation but isostasy fails to account for opposite movements in adjacent areas. Tne thermal cycle hypothesis put forward by Joly may account for such movements.

Crustal Deformations and Associated Structures :—

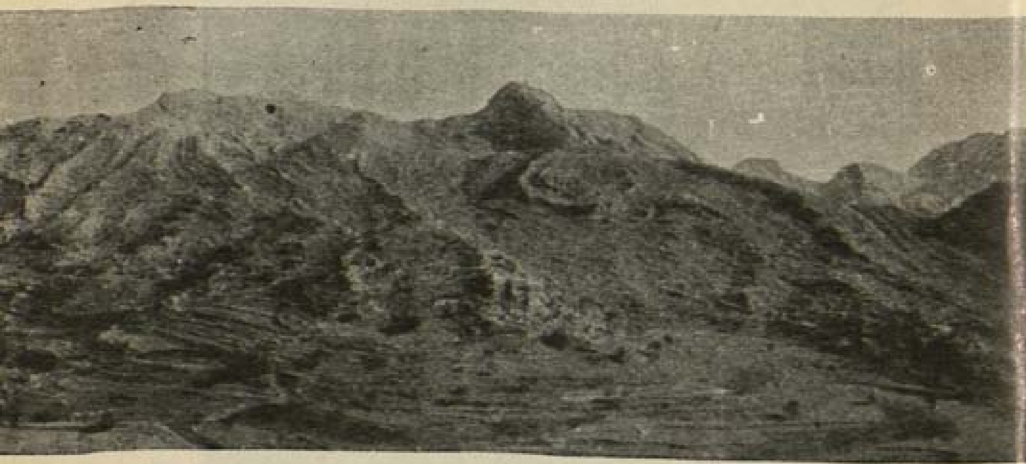
Movements of the parts of the earth's crust are always occuring and their cumulative effects are producing pronounced results. Stresses set up by continued straining produce deformation of the crust when the rocks can bear no more straining. Distinct structural features result from these deformations which form the subject of discussion of this chapter.

Several terms, such as outcrop, dip and strike, will be first

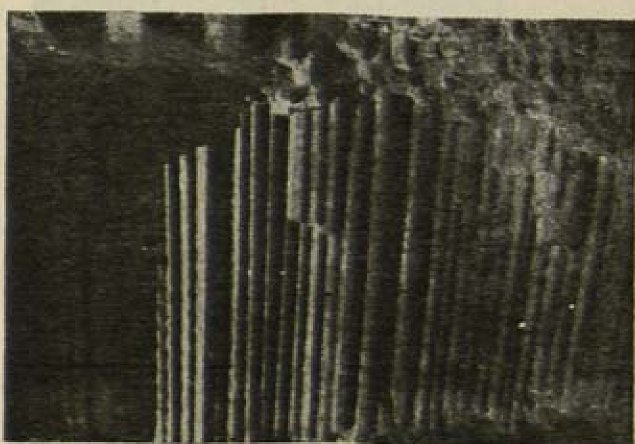


Pl.—24 A panoramic view of the Lonar Lake in Buldana, Bombay

(By courtesy, Director, G.S.I.)



Pl.—25
Overfold in Krol Rocks (*By courtesy, Director, G.S.I.*)

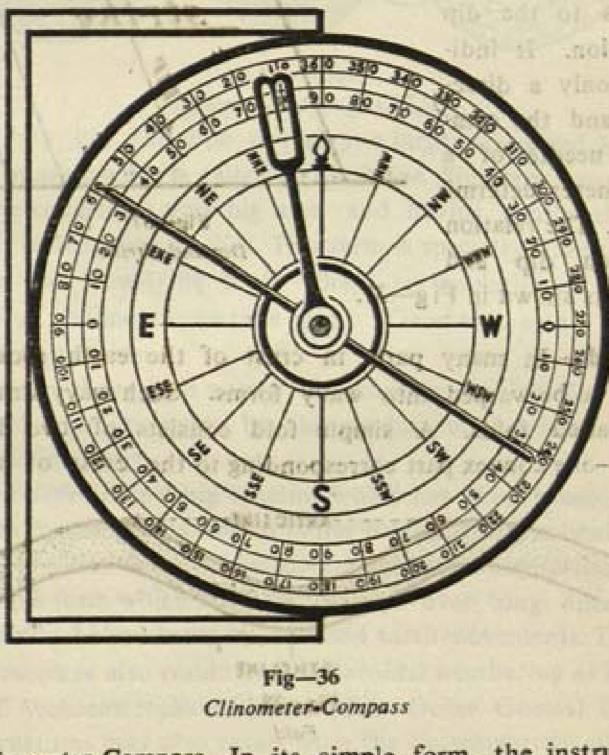


Pl.—26
Culumnar Joints, Andheri

dealt before coming to the proper subject as these will often be used in later pages.

Outcrop—This denotes the area over which a particular bed is exposed upon the surface. The line of intersection of the bounding surfaces of a bed with the surfaces of the earth, marks the limit of it.

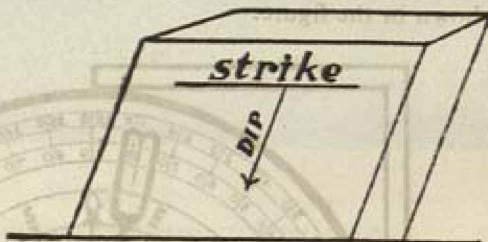
Dip—It is the inclination of a bed with the horizontal plane. The angle is generally measured by an instrument called clinometer and is expressed in degrees with the direction e.g. 25 degrees S.E. A simple form of a clinometer is shown in the figure.



Fig—36
Clinometer-Compass

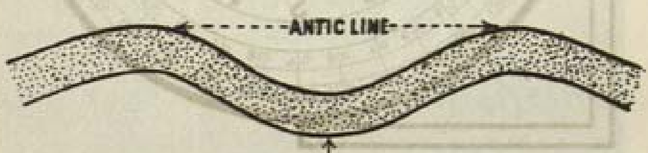
Clinometer-Compass—In its simple form, the instrument consists of a pendulum which moves over a disc graduated in degrees and divided into four quadrants each reading from 0° to 90°. There is a magnetic needle at the centre of the disc which moves over a bigger concentric circle which is graduated from 0° to 360°. There is another small concentric circle which is divided into sixteen parts to give the geographical directions. The clinometer has a stand by means of which it can be placed over an inclined rock and the deviation of the pendulum from 0° gives the amount of the dip and the direction is obtained from the innermost smaller circle.

Strike—It is the horizontal line of extension of a bed and is given by the intersecting line between the bed and the horizontal plane. Strike is at right angles to the dip direction. It indicates only a direction and the compass needle of a clinometer determines it. The relation between dip and strike is shown in Fig—37.



Fig—37
Dip and Strike

Folds—In many parts in crust of the earth rocks are found to be warped into wavy forms. Such wavy structures are called folds. A simple fold consists of two distinct parts—one convex part corresponding to the crest of a wave



Fig—38
Fold

and the other concave part corresponding to the trough of a wave form. The crest part of a fold is called an *anticline* and the trough part is called a *syncline*. The accompanying figure will illustrate the form.

Repetition of beds on a map generally represents folding of strata though this may also be due to erosion or faulting. It must be remembered that anticlines and synclines reflect structural features of the crust and not outward surface forms because erosion may make an elevated hill from the synclinal part and a depression from an anticlinal area as shown in Fig. 39

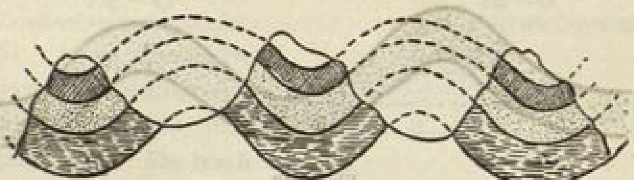


Fig.—39
Effect of erosion upon folds

A very big anticline covering a large region and having gently sloping sides is called a *geanticline*. Similarly a very big syncline covering a very big area and having gently sloping sides is called a *geosyncline*. This term is specially used to denote a vast low-lying basin where accumulation of a thick deposit of sediments can take place. Geosynclines are future sites of mountains.

Anticlinorium—It is a very big anticline which has been rendered more complex by the production of minor folds in the anticlinal part.

Synclinorium—It is a big syncline which has been made more complex by the production of minor folds in the synclinal part.

Dome—It is an upwarp structure corresponding to the crest of a wave form which does not extend over long distances. Domes may be produced by localised earth movements. Dome-like structures also result from spheroidal weathering as in the case of Archaean rocks of India (C.f.—Dome Gneiss) Dome-like structures may also result from the accumulation of lava materials from volcanoes or by the intrusion of salt material in plastic state near the surface of the earth.

Basin—It is a trough-like structure which does not extend over a long distance. The dip of the beds or the slope of the sides is almost radial towards the centre (just opposite to the dome structure). These result from earth movements of comparative minor intensity. Basin-like structures may also result from differential erosion.

Different Types of Folds :—

(1) *Symmetrical folds*—This is the simplest type of folds in

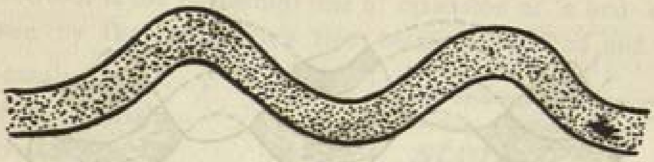


Fig.—40

Symmetrical folds

which an anticline or a syncline is symmetrical about the median plane. This is also called the Jura type of folds.

(2) *Asymmetrical or inclined folds*—In this type of folding

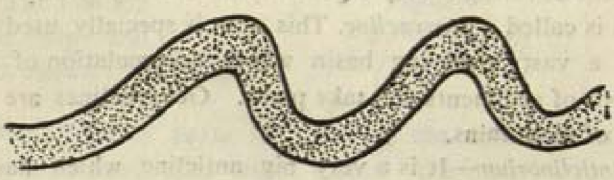


Fig.—41

Asymmetrical folds

the symmetry about the median plane is lost. Such folds are inclined more or less in one direction.

(3) *Overturned folds or overfolds*—In this type of folding one limb or side of an anticline or a syncline is inclined to a great extent towards the other (PL—25).

(4) *Recumbent folds*—This type of folding shows one limb practically resting on another and the two limbs are more or less in a horizontal position.

In an *overthrust*, part of a folded bed is broken and is carried to a great distance. This is a case of faulting though it is produced at a late stage of folding formed by extreme compression.

(5) *Isoclinal folds*—This type of folds shows parallel limbs which may either be vertical or inclined.

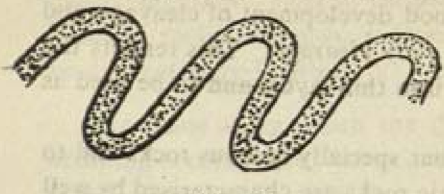
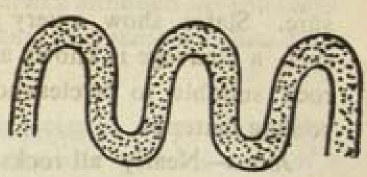


Fig.—42
Isoclinal folds (inclined).



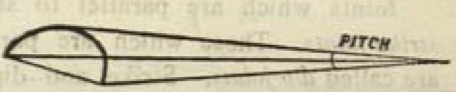
Fig—43
Isoclinal folds (vertical)

(6) *Monocline* — In this type of folding the strata are bent in one direction only. On both sides of the bend the strata are horizontal.

Fig.—44
Monocline

(7) *Homocline*—If there are several beds all dipping in one direction, the resulting structure is called a homocline.

(8) *Pitching fold*—The median line of an anticline or a syncline is its axis. If this axis is inclined to the horizontal plane, the fold becomes a pitching fold and the angle between the axis of the fold and the horizontal plane is called the pitch of the fold.



Fig—45
Pitching fold

Outlier—It is an exposure of an younger bed surrounded by outcrops of older formations. The formation of an outlier is mostly due to erosion but may also result from faulting. The hills in Fig. 39 show outliers.

Inlier—It is an exposure of an older bed surrounded by outcrops of younger formations. As in the case of outlier, it is also due mainly to erosion but may also result from faulting. The valleys in Fig. 39 show inliers.

Cleavage—This indicates in a mineral or a rock easy planes of separation. Minerals and rocks possessing cleavage will break more easily in cleavage directions than in others. Good cleavage does not exist in all minerals and rocks. In minerals it is due to the molecular structure and in rocks it is due to the parallel arrangement of minerals mostly by pressure. Slates show a very good development of cleavage and such a cleavage is known as *slaty cleavage*. This renders the rock suitable to be cleaved into thin layers and to be used as roofing material.

Joints—Nearly all rocks but specially igneous rocks and to some extent some metamorphic rocks are characterised by well developed cracks which are called joints. Joints are common features in rocks like granites, basalts, limestones etc. Joints show practically no displacement of rocks on both sides of them. They are of great practical importance in quarrying. Granites show three sets of joints mutually at right angles. Such joints are called *mural joints*. Basalts show joints which are closely spaced and enclose hexagonal columns. Such joints are called *columnar joints* and are specially exhibited by the basalts of Giant's Causeway of Northern Ireland and of the Isle of Staffa in the Hebrides off Scotland. In India similar examples are obtained from Andheri near Bombay and from Gujri on the Bombay-Agra Road near Maheswar. (PL—26).

Joints which are parallel to strike directons are called *strike joints*. Those which are parallel to the dip directions are called *dip joints*. Strike and dip joints are only seen in folded and inclined rocks.

Joints which traverse rocks for considerable distances are called *master joints* in contrast to *minor joints* which are of short lengths.

Joints are caused as a result of contraction due to cooling or consolidation of rocks. Sometimes they are also caused by compression or by tension.

They control underground percolation of water and thus determine the water supply at a place and underground solution of rocks. They thus influence weathering processes and determine to a large extent the surface features of a region.

Faults—This is the phenomenon in which there is relative displacement of rocks along the breaking plane. The displacement may be instantaneous or a bit delayed. Their effects are most clear in bedded rocks although all the three kinds of rocks—igneous, sedimentary and metamorphic, may be dislocated by faulting.

The plane along which the displacement takes place after breaking is called the *fault plane*. Strictly speaking it is not a plane surface but may be curved or otherwise irregular. Hence it is better to be called *fault surface*. Such fault surfaces are apt to be highly polished because of the frictional resistance offerred to the displacement of rocks. Such a smoothed and polished fault surface is called *slickenside*. Sometimes the fault surface is full of angular fragments which are produced from both sides by faulting. This is known as *fault breccia or crush breccia*. In the extreme case of crushing the fault surface is marked by a thin deposit of clayey matter which is called *gouge or flucan*. Lower or upper ends of the strata which are involved in faulting are sometimes bent in upper or lower directions. This bent structure produced at the ends of strata by faulting is known as *drag*. As already stated faulting produces relative displacement of rocks. The result is that one part is put to a higher position relative to the other & this may produce a mountain like structure with a steep side. This is called a *fault scarp* (PL—28). This cliff-like part is later modified by erosion. The overhanging part is called the *hanging wall* and the other part is called the *foot wall*.

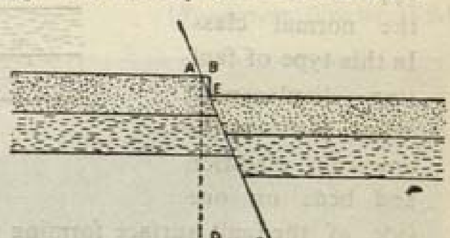


Fig 46
Fault

AB denotes the horizontal displacement and is called the *heave*. BE is called the *throw* which denotes the vertical displacement. It may be in the upward or down waxd direction. Angle CAD is known as the *hade* of the fault. It is the angle which the fault surface makes with the vertical plane. The angle CAB, which the fault surface makes with the horizontal plane, is called the *dip* of the fault. AE which denotes the displacement of a strata is called *displacement or slip.*

Different Types of Faulting :—

(1) *Normal fault*—In this type of faulting, beds on one side of the fault surface forming the hanging wall goes down, after breaking, relative to the other. This is also called the gravity fault. In this type of faults the hade is towards the down throw side.

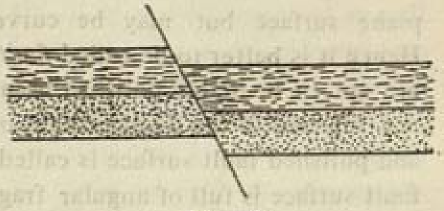


Fig 47
Normal fault

(2) *Reverse (or Reversed) fault*—It is so called as this type of faulting is just the opposite to that of the normal class. In this type of faulting displacement takes place in the upward direction and beds on one side of the fault surface forming the hanging wall are pushed up the fault surface. The hade is here towards the upthrow side.

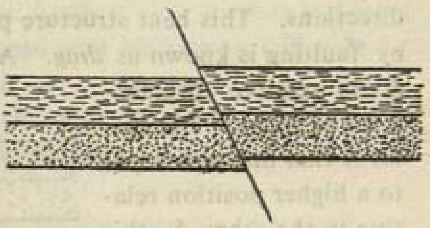
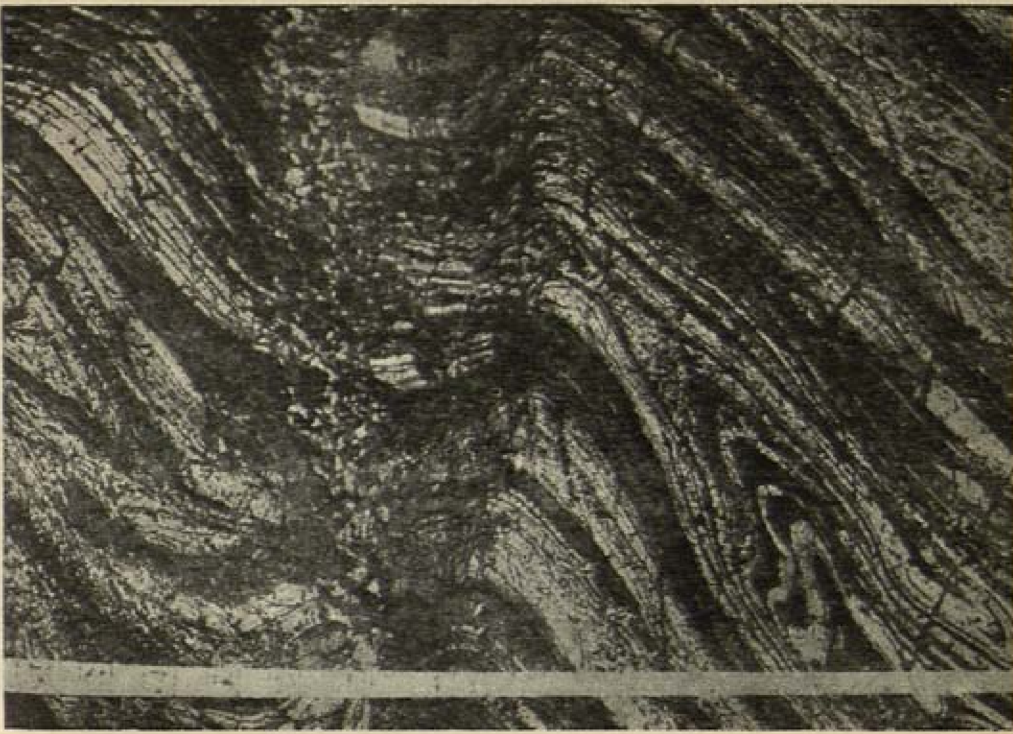


Fig 48
Reverse fault

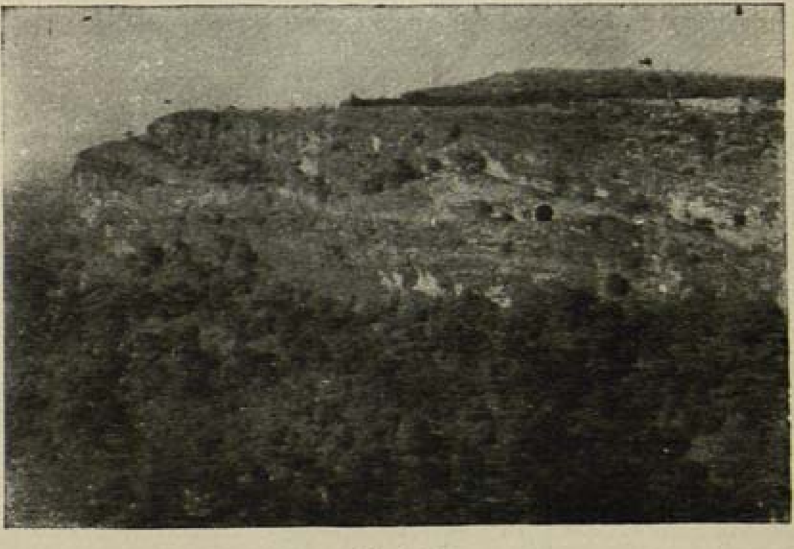
(3) *Dip fault*—This is a type of faulting in which displacement takes place in the dip direction. This type of faulting cuts directly across the strike of the strata involved in faulting.

(4) *Strike fault*—In this type the faulting takes place in the strike direction of the strata involved. The strike of the fault and that of the strata are parallel.



Pl—27 Folding and faulting with fault breccia, Kurhadi Nadi, Raikela

(By courtesy, Director, G.S.I.)



Pl.—28

Reverse fault in Up. Kaimur Rocks

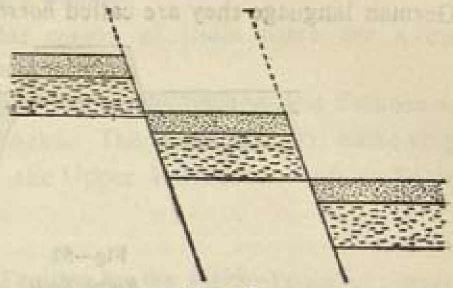
(By courtesy, Director, G.S.I.)

Pl.—29 A view of the Kanchanjungha from Sikkim *(By courtesy, Director, G.S.I)*

Pl.—30 Volcanic agglomerate, West Spur of Dalma Hills *(By courtesy, Director, G.S.I.)*

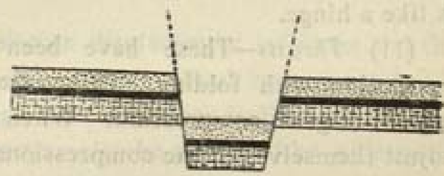
(5) *Oblique fault*—This type shows displacement across the strike of the strata in any direction.

(6) *Step fault*—Faults may be grouped together in an area. Several parallel normal faults all producing throw in the same direction, will make a stair-like aspect. Such a type of faulting is called step faulting.



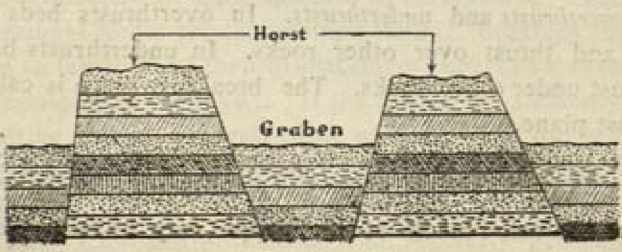
Fig—49
Step fault

(7) *Trough (or Trench) fault*—If there be two series of step faults which converge or tend to converge, the resulting structure is the formation of a trough or a trench. Hence this type of faulting is called trough faulting or trench faulting. In German language the trough or trench so produced is called *graben*. If the troughs extend to great distances and have considerable magnitude they are called *rift valleys*, as for example the Rift Valley of East Africa.



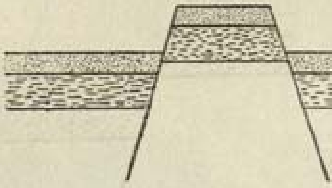
Fig—50
Trough fault or Trench fault

(8) *Ridge fault*—If there be two series of step faults which diverge, the resulting structure is the formation of a ridge.



Fig—51
Horst and graben

Such a type of faulting is therefore called ridge faulting. In German language they are called *horsts*.



Fig—52
Ridge fault

(9) *Rotary fault* (*Also called scissors fault*)—Faulting is sometimes attended by a sight pivotal motion thus producing down-throw at one end and an up-throw at the other end of the strata. Such a type of faulting is known as a rotary fault.

(10) *Hinge fault*—It is a type of faulting which shows displacement at one end but the other end remains at its original place. The name is so because the structure produced is like a hinge.

(11) *Thrusts*—These have been already mentioned in connection with folding. These are generally frequent in regions of great compression. When the beds can no longer adjust themselves to the compressional forces, breaking takes place and this results in the formation of low angled faults in which the relative displacements of beds are very wide. Such types of faults are called thrusts. They are conspicuous features in regions of fold mountains. Thrusts are of two kinds—*overthrusts* and *underthrusts*. In overthrusts beds are broken and thrust over other rocks. In underthrusts beds are thrust under other rocks. The breaking plane is called the thrust plane.

Nappe is a French term which is used to denote rock sheets brought forward by a thrust or by a recumbent fold. Due to subaerial erosion much of the nappe may be eroded at a later date but here and there a few exposures of the old nappe may be seen which have escaped erosion. Such part of a nappe is called a *klippe* (a German term meaning cliff).

Erosion may expose rocks below a nappe mass. Such an eroded rock gap is called a *window*.

In the Extra-Peninsular region of India there are a few well studied nappe regions.

In Simla region the Krol nappe has pushed the Palaeozoic rocks over the Tertiary rocks. The lower Tertiary rocks crop out as windows through the Upper Palaeozoic beds in Solon and Subathu areas.

Signs of Folding and Faulting in the Field—Detailed observation in the field can only detect folding and faulting. The following may prove useful.

In favourable sections folding can be easily detected. From the wavy surface in a region folding may be detected. If a bed dips in two opposite directions folding is the inference. Sudden changes in the thickness of beds may be the result of folding and faulting too. On the map repetition of beds means folding though this may also be produduced by erosion.

Faulting with its relative displacement of rocks and the drag can also be seen at some places. Faulting can not be so easily detected as folding. In some cases fault scarp may indicate faulting but scarps may also be produced by differential erosion.

Causes of Folding and Faulting—Compressional forces acting tangentially to the surface of the earth are responsible for the production of folds and also of reverse and thrust faults. Tensional forces produce normal faults. Breaking takes place due to tension and then displacement occurs as a result of the attraction due to gravity. If the forces be suddenly applied faulting is the general effect whereas if the forces be slowly applied folding may take place. Folding and faulting are however manifestations of the forces which are deep-seated in nature. Continental drifting, radio-actively generated heat, convection currents in the subcrustal regions, isostatic adjustment etc. may be the ultimate causes.

CHAPTER XIII

MOUNTAINS AND THEIR ORIGIN

Mountains may be generally divided into three types—(i) *Accumulation type*, (ii) *Relict or Residual type and* (iii) *Deformation type*.

The agencies involved in mountain-making processes are (i) *volcanic activity*, (ii) *differential erosion or* (iii) *crustal movements*. Commonly two or more processes combine to produce complex results.

Accumulation of volcanic materials such as lava etc. into heaps or cones produce volcanic mountains. Such mountains and sand dunes are examples of accumulation type of mountains.

Differential erosion may cause the formation of mountains This is specially noticeable in regions which are composed of materials of differing solubility. Plateau remnants are the examples of relict type of mountains. (Plateau is an elevated area generally over 1000 ft. in height with a more or less flat top. They are of two types—(a) *volcanic plateau* as for example the Deccan Plateau, and (b) *erosion plateau* as for example the Chotanagpur Plateau in Bihar.)

The deformation type of mountains can again be divided into two types—(a) *fault type* of mountains and (b) *fold type* of mountains.

Fault mountains are produced by both normal and reverse type of faulting. They are also called *block mountains*. Sometimes adjacent faults may produce an intervening raised ridge and adjoining low-lands. Such raised parts and depressed areas are called *horsts and grabens* respectively. The Fig.—51 illustrates the idea.

By far the most important type of mountains is the fold type. In the formation of fold type of mountains several distinct stages are noticed which are :—

(a) Initial stage—When the accumulation of sediments in a subsiding geosyncline takes place.

(b) Youth stage—When the sediments are strongly folded and faulted.

(c) Mature stage—When the surface features are impressed by erosion.

The first stage in the formation of a mountain is the existence of a long trough of shallow depth of water, which is called a geosyncline.

Into such a trough sediments are brought from the sides and deposited. With continued sedimentation the floor of the geosyncline begins to sink down under the load of sediments. When the floor sinks down the two sides approach each other and thereby the trough becomes more deepened. With the narrowing of the trough and sedimentation, the geosynclinal trough becomes nearly filled. There is a limit to the sinking of the geosyncline because the upper lighter material can not sink down to indefinite depth into the lower heavier material. After some time the subsidence stops and with the narrowing of the floor the sedimentary piles are thrown into folds. Folding and thrust-faulting take place and as a result a complex fold system of mountains originates. The uplift is due to isostatic adjustment, compressional force; expansion, due to heat, of the geosynclinal material that has gone down etc. Later the agents of erosion sculpture the elevated mountain mass and form peaks, valleys etc. with the production of the grandeur of a typical mountain. With the lapse of time the mountain mass will be eroded completely, unless crustal movements oppose the levelli ng action of the eroding agents, and the sediments deposited into basin may again form a mountain at a later period. In this way the mountain making cycle may be perpetuated.

Ultimate Causes of Mountain Building—Compressional forces are responsible for the formation of the fold type of mountains which is the most common type of mountains. Various explanations and ideas have been put forward to account for the uplift of the mountain masses. They are :—

(1) *Contraction hypothesis*—This states that the earth

through radiation of heat, is cooling and as a result the earth will shrink and wrinkles will be developed on its surface just as a mango, if left exposed to heat, will shrink and develop wrinkles upon its surface. But with the discovery of the fact that the radio-active substances generally produce heat on disintegration, this idea has lost much of its popularity.

(2) Some hold that under the load of sediments the floor of the subsiding geosynclinal basin, is likely to be broken and thus sediments would meet the internal heat and would expand in volume, as a result the upper sedimentary layers would be uplifted. This process, if in operation, would account for the vertical uplift only but not the compressional forces. This may come into operation during the late stage of mountain-building.

(3) When the geosynclinal basin, on receiving the sedimentary load, will sink down, the two sides of the shallow trough will be brought nearer. This will generate compressional forces and may account for the formation of fold mountains.

(4) Isostatic adjustment is believed to play an important part in mountain-building but the process only accounts for vertical uplift and not the compressional forces. Its part, though considerable, may be held to be subordinate.

(5) Continental drift hypothesis accounts well for the mountain-building processes. The equator-ward force according to Wegener is responsible for the origin of the Alpine-Himalayan chain of mountains and the west-ward force is responsible for the formation of the Rockies and the Andes.

(6) *Thermal Cycle Hypothesis*—Joly is the propounder of this hypothesis. He states that the sial block is floating over the simatic layer. This layer of sima contains an appreciable quantity of radio-active elements. These elements are such as they spontaneously disintegrate by emitting rays and are changed to some other element. Lead is commonly the final product. During this transmutation a great amount of heat is generated. The sial block is even richer in the content of radio active elements. It is believed that there is a rapid fall in the

content of radio-active elements with depth. This may be due to the fact that radio-active elements might have been carried by volatile matters along with the residual magma forming the upper granitic sial layer. The radio-active elements inspite of their high atomic weights were thus carried upwards during the differentiation of the earth's silicate layer into acid, intermediate and basic rocks during the condensation of the earth. This radio-actively generated heat in the sial layer compensates much of the loss of heat by radiation at the earth's surface and the heat generated in the simatic layer goes on accumulating. As a result it will ultimately melt rocks at that particular place of accumulation. The density of the rock material of that place will then decrease and the upper sial block will sink down in the molten sima. The accumulated heat escapes in course of time through the floor of the oceans and the sial block is buoyed up. Again with accumulation of heat the sial block will sink in the sima and again with the escape of heat it will rise up. This cycle which is controlled by radio-actively generated heat is called Joly's thermal cycle after the name of the propounder. This also offers an explanation for the cause of mountain-building. During the melting of the sima, the sial layer will be in a state of tension and with the escape of heat, shrinkage of the sima, due to solidification, will start and the sial layer in order to accomodate itself to the shrinking simatic layer will be thrown into folds.

(7) *Convection Current Hypothesis*—According to Holmes there is a convection current from the equator to the poles in the subcrustal region which causes crustal deformation responsible for mountain-building. The radio-actively generated heat in the simatic layer will make it molten and will allow the flow of convection currents.

Igneous Activity during Mountain Building—Formation of complex fold mountains is generally associated with the intrusion and extrusion of magma. The magmatic intrusion and extrusion may be due to the increase and reduction of pressure as a consequence of the uplift of the sedimentary pile. Batholiths of granite are generally associated with complex fold mountains. These granitic cores are sometimes laid bare by deep erosion. The batholiths are generally associated with sills, dykes etc. the formation of which is due to the intrusion of magma into the planes of weakness in the mountain rocks. Sometimes even extrusion of magma takes place with the resultant volcanic activity.

The Himalayas—The Himalayas extend from the Indus bend on the north-western part to the Brahmaputra bend on the north-eastern part of India. These are series of parallel mountain chains separated by valleys or plateaus. The width varies from 100 to 250 miles whereas the length is nearly 1500 miles. The mountains have clear geological and structural affinity with the Baluchistan and Burmese mountains.

Division of the Himalayas .—

A. Geographical Section.

(1) Transverse section according to Burrard—

(a) The Punjab Himalayas—Length 350 miles from the Indus bend near Gilgit to the Sutlej River. Nanga Parbat (26,620 ft.) is the highest peak in this part of the Himalayas. The Pir Panjal is a southernly branch from it.

(b) The Kumaon Himalayas—Length 200 miles from the Sutlej River to the River Kali. Nanda Devi (25,645 ft.) is the highest peak here. Other noted peaks are Trisul (23,360 ft.), Badrinath (23,190 ft.), Kedarnath (22,770 ft.), Gangotri (21,700 ft.) etc. The Ganges originates from the region near Gangotri. The Dhauladhar Range is the southern branch from it.

(c) The Nepal Himalayas—Length 500 miles from the River Kali to the River Teesta. The highest peak of the world Mount Everest (29,141 ft.)[1] is situated in this part. It was named after Sir George Everest, once Director-General of the Survey of India. Other noted peaks here are

1. A recent (1954) survey gives Mt. Everest a height of 29028±10 ft.

Kanchanjungha (28,146 ft.), Dhaulagiri (26,795 ft.), Gosianthan (26,291 ft.) etc.

(b) The Assam Himalayas—Length 450 miles from the River Teesta to the Brahmaputra bend near Namcha Barwa Noted peaks are Namcha Barwa (25,445 ft.), Kula Kangri (24,784 ft.) etc.

(2) Longitudinal section—

(a) The Outer Himalayas or the Siwalik Hills—Width varies from 5 to 30 miles; average height 3000 ft. This region is swampy and forest-clad as for example the Duars in North Bengal and Terai region in Nepal.

(b) The Lesser or Middle Himalayas. Width varies from 40 to 50 miles. Height varies from 12,000 ft. to 15,000 ft.

(c) The Great or the Central Himalayas—The average height is 20,000 ft. The highest peaks occur in this region.

(d) The Trans-Himalayas or the Tibetan Himalayas—Average width about 25 miles. It contains river valleys at altitudes of 14,000 ft.

B. Geological Sections : Longitudinal section based on geological structure and age of the component rocks. They do not exactly correspond to the geographical longitudinal sections.

(1) The Outer or the Siwalik Himalayas consisting of Tertiary rocks only.

(2) The Lesser or the Sub-Himalayas consisting of rocks of Pre-Cambrian to Tertiary age. These are separated from the Siwalik rocks by the Main Boundary Fault. The region is highly complicated due to overthrusting.

(3) The Central or the Main Himalayas consisting of crystalline and metamorphic rocks of Purana (Algonkian to Torridonian) age.

(4) The Tibetan Himalayas consisting of marine fossiliferous rocks of Cambrian to Eocene age.

Structure of the Himalayas—The structure of the Himalayas is not quite known because of the fact that much of the Himalayan area is yet unexplored. Our knowledge of the

Himalayas is due to several expeditions and the work of some geologists noted among whom are Dr. Pilgrim, Dr. West, D.N. Wadia, Dr. J. B. Auden, H. H. Hayden, R. D. Oldham, S. Burrard etc. The eastern part of the Himalayas, from Kumaon eastwards, is practically unknown. This is due largely to the inaccessibility to the place and inclemency of the climate. In the eastern part the Himalayas rise abruptly from the plain and attains high altitude near the plain practically. The foot hill zone is very narrow. In the western part however the Himalayas rise slowly from the plain and the highest region is quite at a great distance from the plain. The western part of the Himalayas shows the following structural belts—

(1) Outer and Sub-Himalayas—A zone of Tertiary rocks. It consists of two belts :—

(a) *Siwalik belt*—consisting of river deposits of Mid. Miocene to Lower Pleistocene age. This persists throughout the foot-hill region of the Himalayas and shows simple types of folding.

(b) *Sirmur belt*—This persists from Naini Tal north-westwards. It is absent east of Naini Tal. It is made up of old Tertiary lagoon deposits which show isoclinal folds.

The Siwalik belt is separated from the older rocks by the Main Boundary Fault.

(2) Central Himalayas—

(c) *Autochthonous belt* (i.e. occuring at the same place)—This consists of rocks of the age of Carboniferous to Eocene and shows recumbent folds in which these rocks have overrided the Tertiary rocks to the south. In the western part of the Himalayas, these overfolds are of Eocene rocks with Carboniferous to Triassic core such as the Panjal Volcanic rocks or the Krol rocks. In the eastern part Lower Gondwana strips are overfolded on the Siwaliks.

(d) *Purana nappe belt*—Unfossiliferous slate rocks are overthrust on the autochthonous belt in the western part.

(e) *Crystalline nappe belt*—It is composed of crystalline and highly metamorphosed older rocks with granitic intrusions of various ages. This belt represents the root zone of the nappes. They are also overthurst on the autochthonous and Purana belts.

(3) Trans-Himalayas—

(f) *Trans-Himalayan or Tibetan belt*—It consists of marine fossiliferous rocks of Cambrian to Eocene age in the Tethyan basin with a few breaks. It shows simple folds but a portion has been overthurst on the crystalline, Purana and autohthonous belts in Kashmir area.

Each of these structural belts is separate from the next one by a thrust plane of a recumbent strike fault that dips northwards. It has caused the older northern rocks to override on the younger southern rocks.

In the structure of the Himalayas the following peculiarities are to be noted—

(1) The *general strike* of the mountains is NW-SE. The strike of the folds is parallel to this direction.

(3) The *syntaxial bends* at NE and NW Himalayas. There are two bends of the Himalayan chain of mountains, one occuring at NW part near the Nanga Parbat and Gilgit just where the Indus takes a bend, and the other occuring at the NE part in the Mishmi country in Assam where the Brahmaputra takes a bend to the south. At the NW corner the general strike of the mountains changes from NW—SE to South first and then to the SW. The folded mountains take a knee-bend turning at this point. Similarly at the NE corner the strike bends to the south. These two bends are called syntaxial bends. These are due to the under-thrust of the wedge-like masses of the Peninsular India into the Tethyan sediments which made the Himalayan chains.

(3) *Arcuate disposition*—The convexity is towards the Peninsular India and concavity towards Tibet. Peninsular side is steeper while Tibetan side shows gentle slopes.

(4) The *Main Boundary Fault*—This is a series of reversed strike faults throughout the length of the Himalayas. This marks the boundary between the Siwalik rocks and older ones. The Siwalik rocks are confined generally (with a few exceptions) to the south of the main boundary fault and the

older rocks to the north of it. This marks, so to say, the boundary of these two types of rocks. Hence is the name. Their reversed nature has made the superposition of strata reverse with the younger ones resting below the older, i.e. the Siwaliks resting under the Sirmurs and the Sirmurs resting under still older rocks. This is a conspicuous feature of the outer Himalayas.

(5) *Transverse gorges*—These are deep gorges cut by some Himalayan rivers just across the mountain ranges. They have been discussed in greater detail in the drainage system of the Extra-Peninsula (Chapter VI).

Origin of the Himalayas—The origin of the Himalayas is a history of the formation of a complex fold system of mountains. In the Mid. Palaeozoic time there were two huge continents—one Gondwanaland in the southern hemisphere comprising Brazil, Guinea, Uruguay, Africa, Madagascar, Peninsular India, Western and Central Australia and Antarctica and the other Laurasia in northern hemisphere comprising Central and Eastern Canada, Greenland, Fenno-Scandia, North and Central Siberia, North-East of Siberia and probably Southern China and Indochina. These two continental units were separated by an east-west running ocean which received the name Tethys of which the present Mediterranean Ocean is the remnant. The Tethys varied in extent and depth from time to time. Sedimentation from the Gondwana side and Lauratian side was going on in the Tethyan basin from the earliest time. The evolutionary history of the Himalayas followed the same episode as a fold system of mountain follows.

According to Eduard Suess, a noted Austrian geologist, the pressure, leading to the uplift of the pile of sediments in the Tethyan basin to the Himalayan height, came from Tibetan side while the Peninsular India on the south remained passive. This seems quite plausible from the arcuate disposition of the Himalayan chain of mountains, the convex side of the arc being towards Peninsular India. But P. Lake has shown from the arcuate disposition of the mountains facing the Pacific Ocean in the east coast of Asia, that Central Asia, seems to flow in the eastern direction also. The simultaneous movement of the Central Asiatic mass to radial directions is unacceptable. Moreover Central Asia is a region of excess of matter whereas if the radial movement is to be accepted, it ought to have been a region of deficiency of matter. The only explanation which can be accepted is that the Penninsular India has made an underthrust in the north towards the Central Asia thereby uplifting the sediments of the Tethyan basin and originating the Himalayas.

The Tethys was obliterated in the Tertiary period. The uplift of the Himalayan mass was effected by four great impulses. The first came in the Upper Eocene time, the second in Middle Miocene, the third in Upper Pliocene and the fourth in late Pleistocene. The second upheaval was the most powerful of these four. The Tethys was practically obliterated after this but a linear trough throughout the length of the foot of the Himalayas remained where the Siwalik system of rocks was formed. After the third upheaval this disappeared also. The fourth one was rather weak in comparison with the former ones. Minor earth movements occurred in recent times. The Himalayas are still rising.

The Indo-Gangetic Plain :—

Physiographically India can be divided into three regions—1. *Peninsular India,* 2. *Indo-Gangetic Plain and* 3. *Extra-Peninsular India or Himalayan region.* The second includes the vast fertile alluvial tract of the Indus, the Ganges and the Brahmaputra systems. The rest of India, excluding the Indo-Gangetic Plain and the Himalayan region comes under the Peninsular India.

The Indo-Gangetic Plain covers nearly half of Assam, most of Bengal, parts of Bihar, practically the whole of Uttar Pradesh and the Punjab, Northern Rajasthan and most of Sind. It spreads over an area of nearly 3,00,000 square miles. Width varies from 90 miles in the east to 300 miles in the west. The depth is maximum between Delhi and the Rajmahal Hills in Bihar but is quite shallow in Bengal and Assam. The depth is estimated to be nearly 6,000 ft. or a bit more from geodetic conclusions. Borings have reached more than 2,000 ft. but have not got the rocky bottom. This alluvial tract is composed of Pleistocene and recent deposits of clay and sand with occasional peat beds. Two ridges have been made out under the alluvium—one is the Delhi Ridge which is an extension of the Aravalli strike and the other is in direction of Delhi and the Salt Range. Kirana and Sangla are the outliers of the last one.

Origin—According to Suess the Indo-Gangetic Plain has been formed by the filling up of a depressed area which was formed as a foredeep in front of the upheaved Tethyan sediments. According to this view massive Peninsular India remained passive and offerred resistance to the southernly advancing pile of sediments as a result of the pressure from the northern Tibetan side which caused these foredeeps. These deeps were later filled up by sediments carried from both the northern newly upheaved Himalayan side and the southern Peninsular India.

According to Sydney Burrard, late Surveyor General of India, the Indo-Gangetic depression is of the nature of a rift valley. A rift valley is a structure bounded longitudinally by parallel sides and is formed by the faulting of a huge linear tract between two parallel fault lines. Sedimentation into such a rift valley has produced the Indo-Gangetic Plain. This view has got few geological evidences in favour and is based only on geodetic observations.

According to a third view the Indo-Gangetic Plain has been formed by the filling up of a basin of the nature of a geosyncline. Continued sedimentation was increasing the load and the basin was sinking concurrently as a result of isostatic adjustment. This subsidence has given rise to the enormous thickness of the sediments. This is quite in keeping with the geological processes.

Other Mountain Ranges of India—Extra-Peninsular Region.—

Karakoram—Starting from the Tibetan Plateau, (the highest plateau in the world with an elevation of 16,000 ft.), if we proceed southwards we shall meet a number of ranges in succession. These mountains are more or less parallel to the Himalayan chain. First we shall meet the Karakoram Range. This starts from the Pamir Plateau (elevation 12,000 ft.), west of the Tibetan Plateau. The Hindukush Mountain to the north of Afghanistan also starts from the same Pamir Plateau and is more or less in continuation with the Karakoram Range. The Karakoram carries the world's second peak—the K_2 or the Mount Godwin Austen with an altitude of 28,250 ft.

Kailash Range—As we proceed southwards we shall come across first the Aling Kangri, then the Trans-Himalayan Range and the Kailash and the Ladak Ranges. Occuring in the middle portion to the north of the Himalayan Ranges, the Kailash and the Ladak Ranges are closely spaced mountains. This region is notable as the ultimate source of the three important Indian rivers, namely the Indus, the Ganges and the Tsang Po (the Brahmaputra). After these two ranges come the Zanskar Range and finally the Himalayas proper.

The North Western Mountains—These are the mountains separating India from Baluchistan. These Baluchistan ranges are the Sulaiman, the Bugti and the Kirthar Ranges (from north to south). Their strike is transverse to the trend of the Himalayas. The Salt Range of the N.W. Punjab is also more or less parallel to this line of ranges.

South Eastern Mountains—These ranges start from the Himalayas with the Patkoi Hills and continues through the Naga Hills and the Manipur Plateau. There is a westernly branch associated with it. It includes the Jaintia, the Khasi and the Garo Hills. The first branch after the Manipur Plateau continues to Lushai Hills and the Arakan Yoma. (Yoma means a bone-like ridge.) The Arakan Yoma continues upto Cape Negrais but is traceable upto the Andamans, Nicobars and Sumatra.

Peninsular Mountains :—

The Aravalli—This is the oldest mountain range in India. It divides Rajasthan into two parts—one north-western part and the other south-eastern. The trend of the Aravalli is NE—SW. It extends from Gujrat to Delhi but its extension is perceptible into the Laccadives and the Maldives. It is also believed to have extended beyond the Himalayas. Though situated in the way of south-west monsoon, blowing from the Arabian Sea, it can exert very little meteorological influence as it is parallel to the monsoon course. As a result parts of Rajasthan are gradually turning to be desert. It now reaches the highest elevation of 4,000 ft. nearly but in former times it was much higher. The mountain consists of the Aravalli and the Delhi Systems of rocks which are of Huronian and Algonkian age respectively. It was originated as a result of the orogenic movements at the close of the Dharwar time (Huronian) and was upheaved again in later periods probably in Mesozoic time.

The Vindhyan Mountain—This consists of a line of scarps on the southern border of the Central Indian highlands from Indore to Bagelkhand. Rising to an altitude of 2,500 ft. to 4,000 ft. this mountain is composed of rocks of the Vindhyan System (Torridonian). The rocks are mostly sandstone, limestone and shale. The eastern part of the Vindhyan mountain, in Bagelkhand, is known as the Kaimur Range. The trike of the mountain is ENE-WSW.

The Satpuras—Situated in the region between the two rivers, the Narbada and the Tapti, there are several parallel ranges (also parallel to the Vindhyan Mountain) which are called the Satpuras. They start from the Rajpipla Hills in Bombay on the west and extend almost to Bihar. It consists for the most part of the Deccan basalts but other types of rocks also occur in places, such as the Gondwana rocks in the Mahadeva Hills (from Keuper to Rhaetic age) and Archaean rocks in the Maikal Range.

The Eastern Ghats—This is a series of broken and unconnected mountains running from Orissa to the Nilgiri Hills bordering the Bay of Bengal. The Eastern Ghats are relict type of mountains. Notable among the series are the Nallamalai, the Shevaroys and the Nilgiri Hills. Individually the mountains do not show uniformity in component rocks and are of the same geological age. Archaean rocks (Khondalites, Charnockites, and gneisses) and Cuddapah rocks are the most important ones. The general strike is NE—SW. These hills have a coastal plain made up of alluvium which has been formed by the sea waves from these mountains and the coastal area. The north-east monsoon brings rain in winter here. The rainfall is scanty.

The Western Ghats—(Also called the Sahyadris)—The word ghat has come from the peculiar step-like character as a result of weathering of the horizontal layers of the Deccan basalts which cover the major part of the Western Ghats from Goa to the River Tapti. The Western Ghats extend from the Tapti to the southernmost Cape Comorin. The Western Ghats meet the Eastern Ghats in the Nilgiri Hills. Here the rocks have been replaced by the Archaean gneisses (the Charnockites). The Nilgiri Hills reach the second altitude in the Peninsular India in the Dodabetta Peak with an elevation of 8,760 ft. South of the Nilgiri Hills, the Western Ghats after a gap, called the Palghat gap, continue through the Anaimalai Hills having the highest elevation in the Peninsular India in its Anaimudi Peak (8,850 ft.) and the Cardamom Hills to the south. The Cardamom Hills throw off an easternly branch—the Palni Hills. The general strike is more or less N-S. There is a very narrow coastal tract in front of the Western Ghats. This is due to the rigour of the destructive action of sea waves. The rainfall here is considerable due to the obstruction of the south-west monsoon by the Western Ghats.

The Rajmahal Hills—These form an isolated range of high and detached hillocks. The Rajmahal Hills cover an area of 80 miles' length and 30 miles' breadth. The averag e altitude is 1500 ft. The constituent rocks are basalts with intercalations of grits, carbonaceous shale and calcareous and siliceous materials in small quantity.

CHAPTER XIV

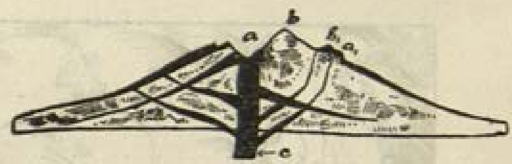
VOLCANOES AND VOLCANISM

Volcanoes are hill-like masses formed around a pipe by the accumulation of molten rock materials and fragmental rocks which are the products of volcanic eruptions. Successive explosions caused by volcanic activity are liable to break the solidified cover and surrounding rocks. The products of explosions accumulate round the pipe through which the molten material or lava, as it is called, forces its way up. The result is that a cone is gradually built up round the pipe. Such conical hill-like masses, formed as a result of explosions and accumulation of the products of explosive activity, are called *volcanoes*.

Fig—53
Volcanic eruption

The explosion accompanied by the pouring out of lava and volcanic gases and blowing of surrounding rock fragments is called a *volcanic eruption*. Volcanoes, which erupt very often, are called *active* volcanoes. Those which show eruptions with the lapse of considerable period between the consecutive eruptions are called *dormant* volcanoes. Dormant volcanoes are likely to show eruptions in near future, while other volcanoes which do not show any volcanic activity within recorded periods of history are known as *extinct* volcanoes. It is impossible to say whether a volcano is extinct or lying in dormant stage as great lengths of time often lapse between consecutive eruptions.

Volcanoes vary in height from the smallest with scarcely 100 ft. height to the Cotopaxi in Ecuador with a height of 19,600 ft.—the highest active volcano in the world. Some extinct volcanoes rise to more heights as the Chimborazo (20,500 ft.) in Ecuador and the Aconcagua (23,000 ft.) near Chile. Some oceanic volcanoes particularly those near the Hawaiian Islands in the Pacific Ocean rise from below the sea level and attain a height of 14,000ft. above the sea level. Adding this to their depths below the sea level, the total height will be over 30,000 ft. that is more than that of the loftiest mountain of the continents.



Fig—54
Volcano

Description of a Volcano—A typical volcano is generally conical in shape. The slope may be gentle at times and steep at other times. At the top of the cone (b) there is a circular pit which is called the *crater* (a). Its diameter varies from a few hundred feet to several miles. The formation of the crater and the volcanic cone is due to the accumulation of the products of explosive volcanic eruptions. The larger fragments of rocks fall near the pipe or the mouth and form gradually a conical ridge round the pipe. As a result, the central region becomes depressed to form a crater. This cone and crater structure is very typical of a volcano. An ideal section will show a pipe or conduit (c) in the central region through which lava makes its way upwards. On its way upwards lava sometimes cuts across the country rocks as dykes instead of taking the usual central pipe. This may be due to either clotting of the former lava and the presence of fissures or planes of weakness in the surrounding rocks. These dykes on coming to the surface also form cone and crater structure at times. These cones are called secondary or parasitic cones (a_1, b_1). Lava sometimes also spreads laterally into the country rock in the form of sills, specially if the country rock be sedimentary. Sometimes at the top of a volcano a huge, more or less circular, pit is found. Such pits are called *calderas* from Spanish source. This pit is to be distinguished from the volcanic crater though the volcanic crater itself may form a part of it. Where as the formation of a crater is due to unequal accumulation of volcanic products round the mouth, the origin of calderas is due either to the explosive violence of volcanic activity resulting in the blowing up of the summit of the volcanic cone or due to the subsidence of a tract along circular fractures as a result of emptying of magma below. The former type of calderas is known as the *explosion caldera* and the latter type is known as the *subsidence caldera.* By the absence of volcanic products in the surrounding region the subsiding origin of a caldera can be inferred. The true nature of a caldera can thus be made out.

Products of Volcanic Activity—Volcanic eruption ejects rock fragments molten lava and volcanic gases.

Solid products—The rock fragments formed by volcanic eruption are called pyroclastic materials or simply *pyroclasts.* These fragmental materials are formed by the explosive violence of volcanic eruptions. The explosive violence of a volcano depends upon the nature and the composition of the magma. If the magma be viscous, it will clot over very easily between successive eruptions and with the next explosion a great quantity of fragmental material will be thrown up. This viscosity of magma again depends upon the chemical composition and the volatile content. Acidic magmas are more viscous than the basic ones. Consequently with acidic magmas fragmental products are more frequent than with basic magmas. The presence of gases lowers the viscosity of magma, but the volatile content is absolutely necessary for the explosiveness. Materials are supplied by the country rock from the side regions of the volcanic cone. Particles of liquid lava are also blown up which after solidification add to the fragmental products. These pyroclastic materials vary widely in size and weight from very minute and light materials to materials as heavy as several hundred tons. These materials have been classified according to size. The bigger angular fragments are known as *volcanic blocks.* If the bigger fragments be somewhat rounded instead of being angular, they are called *volcanic bombs* because of their resemblance to bombs. Their rounded appearance shows their origin from liquid lava. The bombs often present a cracked appearance due to the nearly solid state of the material from which they have been formed. These are known as bread crust bombs as their surfaces present the appearance of a bread. Smaller fragments are called *lapilli* (from a Latin word meaning little stone) or *cinders*. Still smaller fragments are called *volcanic sand, volcanic dust* and *volcanic ash* sucessively. The volcanic dust and ash when consolidated form a rock which is known as *tuff.* The finest particles are often blown to great distances from the volcano by wind. The ashes that fall near the volcanic cone are often washed down by heavy showers of rain which generally-accompany volcanic eruptions. The result is the formation of mud flows. The city of Herculaneum was buried under mud flow following an eruption of the Vesuvius.

The pyroclastic materials are at times very spongy and vesicular in appearance which is due to the escape of gases from the magma out of which the products result. While escaping, these gases often carry little particles and consequently the resultant mass assumes a sponge-like apearance. Several types of pyroclastic materials result in this way. *Pumice* or *Pumice stone* represents the extreme stage of vesicular structure. The magma in this case is so charged with gases that their escape to the atmosphere produces a froth-like product which is extremely light. This froth-like rock material forms a variety of rocks which is called pumice or pumice stone. More generally occuring is the vesicular mass called *scoria.*

The little spaces are gradually filled up by other materials and they assume almond-like shapes. These infillings are called amygdales and the resulting structure is called *amygdaloidal* structure.

The heterogeneous mass of pyroclastic material when more or less consolidated is called *volcanic agglomerate* or *volcanic breccia* (PL—30). The individual fragments are more or less angular. It is to be noted that the soil derived from these rock fragments are highly fertile.

Liquid products—The liquid rock material ejected by a volcano is called *lava.* After the explosive violence has died down, pouring out of lava takes place. The main path of ascension of lava is the volcanic pipe but it also penetrates into the surrounding country as dykes and sills. This is especially the case in the upper region of a volcanic cone as the volcanic cone is not a firm and consolidated region. On the other hand it is formed of loose rock fragments of volcanic activity.

Lava erupted by different volcanoes and at different times varies greatly in chemical composition. Effusive type of granite is called rhyolite, that of syenite is trachyte, that of gabbro is basalt, while those of diorite are called dacite and andesite. The chemical composition of lava is a very important factor in the viscosity of the lava, in the rate of flow and ultimately in the texture and surface features produced from it. The more siliceous ones are more viscous than the basic ones. The basaltic lavas are therefore more fluid and travel to greater distances while the rhyolitic type will have very slower rate of movement and will cover less area. In the case of very fluid magma the lava, even after solidification at the upper surface, may be liquid inside. Consequent draining out of lava will make a tunnel which is called a *lava tunnel*. The more viscous lavas are piled up near the volcanic pipe and form domes of lava and plug-like volcanic necks. The latter stand as pillars after the erosion of the surrounding loose pyroclastic materials that formed the volcanic cone. The slope of the ground is also a factor in the rate of flow of lava.

The composition of lava influences the nature of eruption as well. There are two types of eruptions—one is the *central* type and the other is the *fissure* type or *mass* type of eruptions. The central type of eruption is that in which the eruption of lava comes out from a central vent whereas in a fissure eruption the ejection of lava takes place from a long fissure or a group of parallel or closed spaced fissures. The lava erupted in the former case is of acidic composition, where as in the latter case it is of basaltic composition, is highly fluid and spreads over a great tract of land covering the former surface features. The Deccan trap of Peninsular India is a notable example of this fissure type of eruption. The Deccan trap covers a tract of 200,000 square miles and is 10,000 ft. in maximum thickness. The feeding fissures are filled up at a later period and solidify to form dyke-like masses.

The chemical composition also determines the colour of the resulting rocks. Acidic lavas will produce light coloured rocks whereas basic lavas produce dark coloured rocks.

The texture of the resulting rocks is also influenced by the viscosity of the magma and therefore ultimately by the chemical composition.

Lava on solidification produces different types of surface features which also depend upon the chemical composition of it. Viscous lava presents, after solidification, rugged and rough surface which is formed by the breaking up of the solidified crusts by the motion of the still liquid region below. The resulting mass is called *block lava*. The more fluid lava produces ropy or wavy and smooth surfaces after consolidation. This type of lava is called *ropy lava*. The ropy lava starts with a higher temperature than the block lava.

Pl.—31 Mud Volcano, Yegubwat, Burma.
(*By courtesy, Director, G.S.I.*)

Pl.—32 Central Cone of Barren Island Volcano.

(*By courtesy, Director, G.S.I.*)

Basic lava, such as the spilitic type, often presents a peculiar surface feature resembling pillows when poured into water.

It is to be remembered that chemical composition is also always influenced by the volatile content of lavas which also forms a part of the composition.

The temperature of a lava varies from 1000°—1200°C and is maximum at the upper surface. This is because of the oxidation or other types of chemical actions with gases and other materials at the surface.

Gaseous products—The influence of gaseous products upon the melting point, viscosity and fluidity of magma, the rate of cooling and the resulting texture and vesiculation has already been stated. These gaseous products always accompany volcanic activity.

Steam forms the most important constituent of volcanic gases and contributes nearly 90 p.c. of the total content of volcanic gases. Huge amount of steam rises upward in the form of clouds from a volcano. This steam after cooling in the upper atmosphere causes torrential rain. The atmospheric content of water vapour also adds to it. Such torrential rains are frequent after volcanic outbursts and are responsible for the formation of dangerous mud flows already referred to. Observations reveal that Mount Etna emits 460,000,000 gallons of water from one of its secondary cones.

Other gases are carbon dioxide, nitrogen, sulphur dioxide, hydrogen sulphide, hydrogen, sulphur, chlorine, ammonium and sodium chlorides, carbon monoxide, hydrocarbon gases, boric acid gas, boron compounds, fluorine and phosphorous vapours, arsenic vapours and compounds.

At higher temperatures gases like fluorine, hydrochloric acid vapour, sodium chloride vapour, boron compounds and phosphorous vapour are given off. With falling temperature the gases that come out are sulphur compounds, arsenic compounds etc. and carbon dioxide comes last.

Structures Associated with Volcanic Activity :—

Structural features such as dykes, sills, volcanic necks, lava tunnels, volcanic cones, calderas, parasitic cones etc. have been already referred to. Here are some more associated structures.

Cinder cones—These conical structures are built round a volcanic pipe by the accumulation of the loose fragmentary materials, mostly cinders. Variable amount of ash is always associated with it. The angles of repose vary with ash and cinders. Ash comes to rest at an angle of nearly 30° while the cinders come to rest at an angle 45°. The steepness of the cone varies therefore with the nature of the material. The coarser material will form steeper cones while the finer products will produce low and gently sloping cones. These cinders and ash cones are generally associated with explosive types of erosion. They are smaller in area and more or less round in ground plan.

Lava cones—These cones are in contrast to the former ones. They have gently sloping sides and they cover wider areas. Such cones are built up by quiet type of eruptions by the piling of lava flows one upon another.

Shield volcano is a term which is used to express the very gently sloping lava cones covering wide areas because such lava cones resemble a warrior's shield in appearance, with the central region being slightly convex.

Viscous lavas on the other hand are likely to form dome-shaped masses with steeper sides round the pipe.

Composite cones or Mixed cones—These are intermediate in character and composition between the cinder cones on the one hand and lava cones on the other. They consist of layers of pyroclastic materials with intercalations of lava flows. During the explosive phase fragmental products are blown off and these accumulate round the pipe. During the quite phase of eruption lava piles are poured over these fragmental materials. Such a combination will produce a composite cone. The nature of the volcanic products and the coarseness of the materials determine the steepness of the sides and the area of the cones. Due to rude stratification present in such volcanoes they are also called *strato-volcanoes.*

It sometimes happens that in the cones or calderas of old volcanoes small cones and craters have been formed due to continued volcanic activity. These small cones and craters exactly look like primary volcanic cones and craters, and perform the same function. The Vesuvius, built in the caldera of Monte Somma, is a noted example to this point. The inner cone and crater generally go on increasing in size, ultimately this small cone and crater will exactly gain the size of the original cone and crater of the old volcano. When this stage will come the volcano will be called a *rebuilt volcano*.

Explosion pits—These show in miniature the performance of volcanic activity. In such cases the volcanic activity has only blown up holes and built small cones round the holes. They often form crater lakes. These explosion pits are known as *maars*.

Volcanic plateau—The former structures are associated with the central type of eruptions but these volcanic plateaus are associated with the fissure eruptions. They result from the piling up of lava flows one after another to enormous thickness extending over very wide areas. The Deccan Plateau of Peninsular India is an example.

The following ones are some structures and phenomena which are intimately connected with volcanic activity or which are frequent in volcanic areas.

Fumaroles—The word fumarole has come from a Latin word *fumare* meaning "to smoke." These are fissures or vents through which volcanic gases are ejected. It has been stated previously that a huge quantity of gases accompanies every volcanic eruption. But even after volcanic eruptions, when a volcano remains temporarily inactive or dormant, the volcanic gases are ejected through the volcanic pipe as well as through numerous other fissures and exit holes. These fumarolic gases are very hot and sometimes reach temperatures as nearly as 650°C.

The fumarolic gases are practically the same as the volcanic gases already stated. Steam here also forms the major part and contributes nearly 99 p.c. of the total volume. Other gases are carbon dioxide, hydrochloric acid gas, chlorine vapour, sulphur dioxide, hydrogen sulphide, hydrogen, some hydrocarbon gases such as methane, nitrogen, hydrofluoric acid vapour and boric acid vapour. Fumaroles emitting sulphurous vapour are called *solfataras*, when emitting carbon dioxide they are called *mofettes* and when emitting boric acid vapour they are called *saffioni*. The changes brought about by the reaction with the country rock is called *pneumatolysis*. The more important agents in bringing these changes are fluorine, boron, hydrochloric acid and hydrofluoric acid vapour. The compounds produced are calcium fluoride, apatite, tourmaline etc. Fumaroles also produce some metallic compounds in the volatile state notably as chlorides, fluorides etc. By the decomposition of these fumarolic gases by means of heat or by reaction with the country rocks and these gases or by the mixing of two or more gases, various metallic compounds are produced. These are compounds of iron, lead, copper etc. In 1817 in the Vesuvius region a crack of 3 ft. width was found to be filled with specularite (a scaly variety of hematite). Its formation may be due to the action of the two gases, steam and ferric chloride, according to the following chemical reaction— $Fe_2Cl_6+3H_2O=Fe_2O_3$ (specularite) $+6HCl$.

Galena is also found in the Vesuvius region. Its formation is due perhaps to the reaction between lead chloride and hydrogen sulphide.

$$PbCl_2+H_2S=\underset{\text{(galena)}}{PbS}+2HCl.$$

The most remarkable fumarolic field is the Valley of Ten Thousand Smokes near Mt. Katami in Alaska. It is a natural wonder. Through the fissures of this valley steam and other gases are constantly pouring out.

Apart from the metallic content the fumaroles are important as supply centres of huge amount of steam which may be utilised in generating power. Fumarolic areas of Tuscany, Java, Celebes etc. have produced satisfactory results to this point.

Hot springs—These are fissures or holes through which hot water escapes to the surface. Like fumaroles they are also abundant in volcanic regions, although some are situated in highly crumpled rocks which are faulted or folded. The temperature of the water is varying from that of warm water to that of boiling water. This water generally comes from subsurface water that gets heated in contact with the increased temperature below. Magmatic water may also contribute to a little extent. This is proved by the fact that with seasonal change, the flow of the hot springs also changes. In the rainy season hot springs remain active whereas in the winter and summer seasons i.e. during the dry seasons they turn out to be fumaroles by emitting only heated gases. The heat may be due to some exothermic reactions or radio-activity as radio-active substances are often present in such sprin gs.

Rajghir near Patna and Sitakund near Monghyr in Bihar, Vakreshwar in Birbhum in West Bengal, Lasudra and Vajrabai in Bombay and Manikarna in Kulu and Jwalamukhi in Kangra in Punjab (I) and Tatapani in Poonch in Jammu and Kashmir are noted hot springs.

Waters from hot springs are sometimes highly charged with other materials. These waters carrying a good amount of volatile contents are good solvents of materials. Hence on their way upwards these waters take into solution considerable quantity of soluble materials from the country rock and reaching the upper surface deposit these materials round the supplying holes. Water containing carbon dioxide takes into solution calcium carbonate or limestone. When this water comes upto the surface it deposits the calcium carbonate around the mouth and a cone-like structure or encrustation will be made. This type of calcareous deposit is called *tufa* or *travertine.* When the water contains alkali matters in solution it can take into solution silica which may be deposited afterwards on the surface. Such deposits are called *siliceous sinters.* Such deposits are light and white or gray. Other substances like borax, alum, and sulphur and arsenic compounds are found in such waters.

Geyser—This is a form of hot spring which emits gases and hot vapours at intervals. The eruption of water is remarkably regular and periodic. The classical example is afforded by the Old Faithful geyser in the Yellowstone Park so named because it is faithfully discharging water at average intervals of 65 minutes for many years though it has now become a bit irregular. The height of the water column varies from a few feet to hundreds of feet. In the case of the Old Faithful it is generally 150 ft. The intervals between two consecutive eruptions of water and the duration of the eruption are also variable. They are rather rare and occur only notably in Iceland, New Zealand (Pohutu in New Zealand is the geyser with the world's highest throw of water), Yellowstone Park and California in the United States of America.

At the geyser vents cones are made of deposits from the geyser water. Such deposits are called *geyserite*. Sometimes there are mere encrustations. Every geyser possesses some peculiarity with respect to the interval between consecutive eruptions, the duration of eruptions, height of the water column, etc. These peculiarities are due to variations in heat, water supply and the nature of the feeding pipe.

Bunsen in Iceland, and Allen and Day in the Yellowstone National Park have worked on the periodic eruptions of water from the geysers. Their researches have shown that these geyser actions are due to the influence of pressure on the boiling point of water. At normal atmospheric pressure water boils at 100° C but the increase in pressure raises the boiling point whereas decrease in pressures lowers the boiling point of water and the pressure again varies with depth.

At a particular depth the water may reach the boiling point. If the geyser pipe be straight and wide, then convection current will produce a nearly uniforn temperature and boiling springs will result but if the geyser pipe be zigzag and narrow, convection current is effective only for short lengths of the pipe and hence any uniformity of the temperature of water is not possible. At the bends or at the narrow parts of the pipe steam will collect and when the steam pressure has become considerable a quantity of water above gushes out of the pipe. The pressure is thus relieved and there will be no ejection of water unless and until the steam pressure becomes considerable again. This explains the periodic action of geysers.

Two more structures will be discussed here which, though apparently suggest volcanic origin, have however no connection with volcanic activity. They are meteor crater and mud volcano.

Meteor crater—This looks like an explosion pit at the first sight. Closer examination however reveals no supply pipe and hence betrays its non-volcanic origin. Such a depression is the result of a fall of a big piece of meteoritic stone. The collision of the meteor with the ground produces the depression which now resembles an explosion pit in outward appearance. Generally meteoritic matter is found round this depression. Such a depression is called a meteor crater. As for example the meteor crater of Arizona of the United States of America which is 5000 ft. deep.

Mud volcano—This is a conical structure made up of mud resembling very closely a typical volcano in outward appearance. They occur specially in the petroleum field regions, in Russia, in East Indies, in Arakan Coast, in Minbu and Prome areas and Ramri and Cheduba Islands of Burma and in Mekran Coast of Baluchistan. They rise generally to a height of 30 to 40 ft. but in dry climate they rise to greater heights as in Baluchistan the height is sometimes 300 ft. Through the craters mud, saline water, hydrocarbon gases and traces of petroleum come out gently but at times explosion even takes place (PL—31).

Geographical Distribution of Volcanoes—According to Sapper the number of active volcanoes on the surface of the earth is nearly 430, of which 275 are in the northern hemisphere while 155 fall in the southern hemisphere. Of these some are on land but the greater number is in the sea. The number of extinct and dormant volcanoes will be several thousands at rough guess. Several new volcanoes have made their appearance in recent times, such as the Jorullo in Mexico in 1759, the Izalco in Salvador in 1770 etc. The Pacific Ocean is a region of volcanoes. Not only it is encircled by a ring of volcanoes on the coastal region but also it possesses the greatest number of volcanic islands as well as submarine volcanoes. Generally the volcanoes are situated near the sea with the exception of some African volcanoes. The distribution of volcanoes generally follows regions of weakness of the earth's crust and is parallel to some mountain chains and coastal regions. Volcanoes are arranged more or less in several belts. The belt round the Pacific contains the largest number of active volcanoes and is called the *Ring of Fire*. This belt starts from the Cape Horn of South America and passes through the western coast of America, curves round the Aleutian Islands and then passes through the Japanese Island and continues upto the East Indies Islands. Another belt, with a east west direction, starts from the East Indies where it cuts the former belt, passes through Asia Minor, the Mediterranean region and continues upto the West Indies Islands where it again cuts the first belt. Besides these two belts, volcanoes occur irregularly in Antarctica, Iceland and New Zealand.

Indian Volcanoes—Volcanoes are rare in India. The linear extension of the volcanic belt from the East Indies, when produced north westwards, will include two dormant or extinct volcanoes. They are in the Barren Island in the Bay of Bengal (PL—32), and in the Narcondam Island of the Andaman Archipelago. The volcano in the Barren Island was in eruption in 1795 and 1803. It occupies an area of 3 square miles and is 1000 ft. high. It is even now emitting sulphurous vapours. The volcano in the Narcondam Island was active in Pleistocene and since then it has been dormant. There are several other dormant volcanoes in Burma and one Koh-i-Sultan in the Nuski desert in Western Baluchistan which is now in Pakistan.

Classification of Volcanic Eruptions :

According to the nature and position of the supplying

Pl.—33 Seismogram, Alipore (Calcutta) Observatory.

(By courtesy, Director, G.S.I.)

Pl.—34
Effect of Earthquake
(North Bihar Earthquake, Jan. 15, 1934)
A fissure produced at Sitamari.

Pl.—35
Effect of Earthquake
(North Bihar Earthquake, Jan. 15, 1934)
Distortions of railway lines, Sitamari

(By courtesy, Director, G.S.I.)

Pl.—36 The Merua Meteorite
(By courtesy, Director, G.S I.)

pipe, volcanic eruptions are classified as *central* eruption and *fissure or mass* eruption. This has been already stated.

Depending upon the nature of activity, eruptions are classified as *explosive*, *intermediate* and *quiet*. In an explosive type, the eruption takes place with violent escape of gases and consequent blowing up of the surrounding rock and the production of a huge quantity of fragmental products.

In an intermediate type, the eruption starts with an explosion when a huge quantity of fragmental products are given out and at a later period the explosive action dies down and lava is poured out quietly.

In a quiet type, the eruption only discharges a huge quantity of lava quietly without any explosion.

Eruptions are also classified according to the nature of a particular volcanic eruption for which the names of certain well known volcanoes of the world have been used. They are (from the mildest to the most violent type)—

(1) *Howaiian type*—This is characterised by the quiet discharge of lava without any explosive violence and is the mildest type of volcanic eruption. The lava erupted is mobile and thin and spreads over great areas. Little drops of lava form thread-like masses being blown by wind. These thread-like masses are called Pele's hair, from the name of Pele, the Howaiian goddess of fire. Gases given out are little in quantity and are also discharged very quietly. This type of eruption is exemplified by Howaiian volcanoes and hence the name.

(2) *Strombolian type*—The volcano Stromboli in the Lipari Islands, north of Sicily, shows this type of eruption. Hence the name. In this type the eruption is periodic. With some cessations eruptions take place. The magma is less fluid and particles of lava are blown up into the air to form bombs and scoriaceous fragments. Incandescent masses of gases are given and hence Stromboli is called the Lighthouse of the Mediterranean. At times violent explosions also take place but they are less frequent.

(3) *Vulcanian type*—Volcano, also in the Lipari Islands, exhibits this type of eruption. Hence the name. In this type the erupted magma is very viscous and clots are formed between consecutive explosions. As a result huge quantity of rock fragments is blown during successive eruptions. The gases rise upwards vertically and assume cauliflower-like forms but they are not incandescent as those in the Strombolian type.

(4) *Vesuvian type*—This type of eruption is exhibited by the famous volcano, the Vesuvius near Naples. In this type of eruptions the magma explodes as a result of high gas content. With the eruptions huge quantities of gases ascend in cauliflower-like forms carrying much fragmental materials specially ash.

(5) *Plinian type*—Pliny, the Younger, in his letters to Tacitus described a violent explosion of the Vesuvius. His letters were so descriptive that the most violent type of Vesuvian eruptions is associated with his name. In this type of eruption the cauliflower-like columns of gases rise vertically to great heights. Huge quantities of fragmental products are given out with little or no discharge of lava.

(6) *Pelean type*—This type of eruption is exhibited by the volcano Mont Pelee in Martinique in West Indies. This is the most violent type of all eruptions. The magma is viscous and hence form a hard cover in the volcanic pipe. Lower magma charged with gases forces its way upwards through the sides of the volcanic cone as an avalanche of molten rock material and gases. The gases are ejected more or less horizontally and are dark in colour. The horizontally ejected clouds of gases and lava flows are called *nuees ardente's* in French language.

The above eruptions are associated with the central type of eruptions. The fissures or mass eruptions are very conspicuously shown in the eruptions of Iceland and hence they are called Icelandic type of eruptions.

Origin of Volcanism—The effect of pressure increases with depth in the earth's interior. The pressure effect keeps the subcrustal regions in a viscous state. Any release of pressure which may be caused by the diastrophic movements will melt the rocks below and thereby pockets of magma will be produced in the subcrustal region. This is one of the reason for the occurrence of volcanic belts near the fold mountain belts of the world and the occurrence of igneous activity accompanying major crustal deformations. The magma when formed, will find its way upwards by the pressure of the overlying rocks through fissures, joints, fault planes or bedding planes in the regions above or by melting and digesting the rocks above.

The origin of volcanism is due to the release of pressure at depth and it can be dealt with the explanation for (i) the origin of magma with its high temperature, (ii) origin of volcanic gases and (iii) the extrusion of magma.

Origin of magma—It is believed that the central types of eruptions drain pockets of magma while the fissure types of eruptions may have some connection with the basaltic layer below the crust. Pockets of magma may be produced by the relaxation of pressure locally. Accumulation of radio-actively generated heat may also produce pockets of magma by the melting of rocks. This will also account for the heat. The heat may also come from the hot interior, as it is the common experience that the temperature increases with depth. This heat is in a sense original, being the part left after so many million years of radiation.

It has been observed that a volcano may erupt different types of lavas at different periods and again different volcanoes erupt different types of magmas. These phenomena may be due to magmatic differentiation and assimilation that may take place in a magmatic pocket or in a greater reservoir below supplying different volcanoes.

Origin of volcanic gases—Steam, the most important of the volcanic gases, may result from the descending surface water through the upper part of a volcanic cone. This steam may have a magmatic origin as well. Some amount may be formed by the union of hydrogen of the magma with oxygen or more probably an oxide.

Carbon dioxide may be produced by the heating effects of magma in a limestone region.

Of the other gases like nitrogen, sulphur dioxide (formed from the combustion of sulphur or a sulphide of the magma), hydrogen sulphide, hydrogen, sulphur, chlorine, ammonium and sodium chlorides, carbon monoxide, hydrocarbon gases, boric acid vapour, arsenic vapour, and compounds, phosphorous gases, boron compounds fluorine etc. some are original constituents, some are produced from the reaction of the gases amongst themselves or with the rocks through which they pass and some may also come from the subsurface and descending waters.

Extrusion of magma—Crustal deformation may produce magma on the one hand and on the other it may produce folding and faulting in the upper region and this will lead to the formation of numerous cracks, joints and fissures in the overlying region. These fissures serve as the paths of ascension of the magma. Magma is forced through these cracks by the weight of the overlying rocks. The imprisoned gases are also contributing factors to this point. The energy of the gases will take the magma upon the surface just as water is forced up when a soda water bottle is uncorked.

CHAPTER XV

EARTHQUAKES

An earthquake is a jerking motion in the rocky shell of the earth's crust. As a bell is set into vibration by a blow to its surface or as a pond of water generates waves in all direction when struck by a stone, so also the earth's crust, which has considerable elasticity, is set into tremors by a sudden blow from external and internal causes. The shock produced is sometimes highly disastrous to human life and property. The devastating effects produced by earthquakes can be well perceived from the result of the following well known earthquakes.

(1) The Lisbon earthquake (in Portugal) Nov. 1. 1795 by which 30,000 to 60,000 persons were killed. Most of the city of Lisbon was destroyed. So much loss of life and property was due to the tidal waves produced.

(2) The Naples earthquake (in Italy) in 1857 by which 12,000 persons died.

(3) The Mino-Owari earthquake (in Japan) in 1801 by which the two cities were destroyed and nearly 7,000 persons were killed and 17,000 persons were injured.

(4) The Shillong earthquake (in Assam) on June 12, 1897 by which there was great loss of life and property.

(5) The San Francisco earthquake (in California) in 1906 by which 700 persons were killed and 200,000 persons were rendered homeless.

(6) The Sicily earthquake (in Italy) in 1908 in which 76,000 persons were killed and nearly 100.000 persons injured. Most of the town Messina was destroyed.

(7) The Central Indian earthquake in 1915 by which 30,000 persons were killed and 370 villages and towns were destroyed.

(8) The North and Central Italian earthquake in 1920 by which there was a great loss of life and property.

(9) The Mexican earthquake by which 3,000 persons were killed.

(10) The Tokyo and Yokohama earthquake on September 1, 1923, by which 140,000 lives were lost and enormous damage was done. Practically the whole of Tokyo was destroyed. This is the most devastating earthquake ever known.

(11) The Kansu earthquake (in China) in 1923, when the loss of life was more than 100,000.

(12) The North Bihar earthquake on January 15, 1934 when the loss of life was more than 12,000.

(13) The Quetta earthquake (in Baluchistan) on March 31, 1935, when the loss was more than 60,000.

According to Mallet the earth has lost at least 13,000,000 lives by earthquakes in the past 4,000 years. Fortunately for for us all earthquakes are not devastating and there are many earthquakes which are mere shocks and produce practically no damage. According to Prof. Jones, Japan experiences three shocks per day on the average. It is the land of the rising sun and is also the land of earthquakes.

The science of earthquakes is called *Seismology* which has come from the Greek words *seismos* meaning an earthquake and *logos* meaning science.

Causes of Earthquakes—Earthquakes are, as already stated, jerking movements in the earth caused by a sudden blow. The sudden blow is therefore the immediate cause of the earthquake phenomenon. The jerking movement may be on the other hand, due to exterior as well as interior causes.

Aristotle believed that underground air in its endeavour to come out shakes the earth. Lucretious believed that the collapse of underground caves produced shocks. Magnati in 1688 A.D. proposed the action of wind, water and heat, and the concentration of coaly matter for the cause of earthquakes. It is due to the researches of Mallet, Milne, Reid, Imamura, Omori and others that we have at present a fair knowledge of the science of earthquakes though there are many things yet to be made elear.

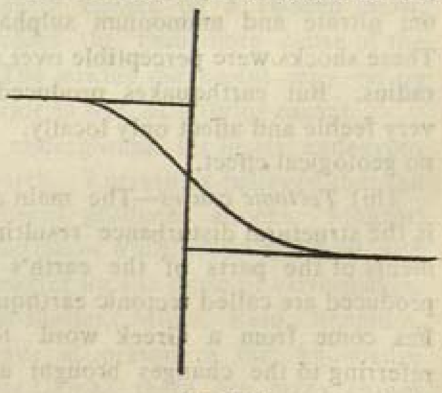
The causes of earthquakes may be divided into three groups—(i) surface causes (ii) volcanic causes and (iii) tectonic causes.

(i) *Surface causes*—Earthquakes may be generated by landslides in mountainous regions. The Turkestan earthquake on February 13, 1911 was believed to be due to a huge landslide in the Pamir region when 500,000 million tons of rock fragments slipped through a length of nearly 2,000 ft. But Oldham has shown that landslides are more often the effect than the cause. Slips on steep coasts, avalanches, underground roof callapse may also produce earthquakes. Differential movements of the parts of the earth along the equator and other places, variations of temperature, variation in the weight of the atmosphere, variation in the distribution of snow and water and the dashing of the sea waves against the coast may also be cited as minor causes producing slight tremors. Slight tremors are often recorded in the Alipore observatory (Calcutta) which are caused by the dashing of sea waves against the Coromandel Coast.

(ii) *Volcanic causes*—Volcanic eruptions can produce earthquakes. Thus the explosion at Krakatoa in Sumatra in 1888, Ischia in the Bay of Naples in 1883 and Bandaisan in Japan in 1888 produced earthquakes. Similarly earthquakes were produced artificially by an explosion of 4500 tons of ammonium nitrate and ammonium sulphate at Oppau in Bavaria. These shocks were perceptible over an area of 300 miles as the radius. But earthquakes produced by volcanic eruptions are very feeble and affect only locally. They produce practically no geological effect.

(iii) *Tectonic causes*—The main cause of the earthquakes is the structural disturbance resulting in the relative displacements of the parts of the earth's crust. Earthquakes thus produced are called tectonic earthquakes. The word tectonic has come from a Greek word *tekton* meaning a builder, referring to the changes brought about in the earth's crust. Most of the disastrous earthquakes are of this kind and occur in places near great fractures. Such earthquakes generally result from sudden yielding to strain produced on the rocks by accumulating stresses. This causes the breaking of rocks and produces relative displacements of rocks. Such faulting causes shaking because displacements of rocks can only be possible by overcoming frictional resistance against the walls of the fault plane. The association of earthquakes with fault lines is an established fact. Generally speaking earthquakes occur in old fault zones. They may also be the result of new ones. Earthquake-shaken areas often bear conspicuous signs of faulting such as displacement of ground in vertical, horizontal and inclined directions. It must be remembered that every earthquake does not produce any visible sign on the surface. Commonly the displacement is too deep to leave any sign on the surface. One example of such earthquake is San Francisco earthquake in California in 1906. This earthquake was the result of a displacement along a great 600 miles long fault zone known as the San Andreas Fault. Horizontal displacement of surface rocks are clearly visible on the surface. The earlier shocks of 1868 and 1872 of this area are also referable to this fault.

Prof. H.F. Reid after a careful study of the San Francisco earthquake of 1906 and of the San Andreas Fault has proposed a new idea for the origin of earthquakes which is the *elastic rebound hypothesis*. According to him stresses on the two sides of the fault plane were accumulating and produced bending of rocks. When the rocks could bear no more straining, breaking with sudden displacement of the elastic rocks on the two side of the fault took place producing a blow to the upper rocks on one side of the fault-plane and to the lower rocks on the other side as shown in the figure.



Fig—55
Elastic rebound

In Assam earthquake (1897) a vertical displacement of 35 ft. in places occurred along the Chidrang Fault running for a length of nearly 12 miles in NNW-SSE direction. Tilting was also noticed in a tract in Cutch as a result of an earthquake occurring on June 16, 1819.

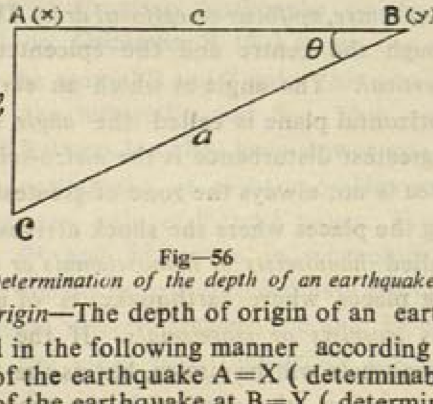
Submarine Earthquakes—Earthquakes often occur under the sea water on the beds of the seas. Such earthquakes can not spread very far in water. They are only to be perceived by a passing ship and can be recorded by seismographs. But their effects on the sea waves are considerable. Vertical displacement on the sea bottom causes huge sea waves known as *tsunamis* in Japanese language, which produce devastating effects on the sea coasts. In open oceans their heights are scarcely preceptible but in length they are 100 to 200 miles and in speed they range from 300 to 500 miles per hour. Such tsunamis often damage the Japanese coast, as in 1703 and 1896. The Lisbon earthquake in 1755 which originated from a submarine displacement caused a great tsunami as high as 40 ft.

Classification of tectonic earthquakes—Tectonic earthquakes may be classified according to the depth of origin.

(1) *Earthquakes of normal or shallow depth*—When the origin is at a depth of 0 to 30 miles.

(2) *Earthquakes of intermediate depth*—When the origin is at a depth of 30 to 150 miles.

(3) *Deep earthquakes*—When the origin is at a depth of 150 to 450 miles.



Fig—56
Determination of the depth of an earthquake

Depth of origin—The depth of origin of an earthquake can be determined in the following manner according to Oldham

Intensity of the earthquake A=X (determinable).

Intensity of the earthquake at B=Y (determinable).

Distance between A and B=C (determinable).

By the inverse square law (i.e. the intensity varies inversely as the square of the distance)

$$\frac{y}{x} = \frac{b^2}{a^2} = \sin^2\theta$$

∴ The angle θ can be determined.

∴ Depth of origin = b = AC = c tan θ.

There is a conflict of opinion among the seismologists as to the depth of origin of earthquakes. Some say the origin is very deep, others hold they are shallow in origin. It is probable that the origin of tectonic earthquakes is generally deepseated, more than 100 miles deep from the surface. These can produce effects over wide areas whereas volcanic ones are quite shallow in origin. Thus G.W. Walker puts the origin of the Pulkova (near Leningrad) earthquake at 800 miles nearly. R. D. Oldham puts the origin of the the Assam earthquake of 1897 to a depth between 100 to 200 miles. Prof. H. H. Turner holds that majority of earthquakes are deep-seated in origin, more than 100 miles, to which the Japanese seismologist K. Wadati agrees.

Mode of Propagation—The place from which an earthquake starts is known as the *focus, origin, hypocentre or centrum.* It should be remembered that the focus is not a point but is often a lengthy tract. The area vertically on the surface over the focus is called the *epicentre, epifocus or epifocal area.* The vertical line passing through the centre and the epicentre is known as the *seismic vertical.* The angle at which an earthquake wave meets the horizontal plane is called the *angle of emergence.* The area of greatest disturbance is the *meizo-seismic* area. The epicentral area is not always the zone of greatest disturbance. Lines joining the places where the shock arrives at the same time are called *homoseists or homoseismals or coseismals* and lines joining places where earthquake is of equal intensity is known as *isoseists or isoseismals.* If the focus be at a point, the coseismals will be circles, but as the focus is a tract rather than a point, the coseismals are generally elliptical.

From a study of the distribution of homoseismals and isoseismals the epicentre can be determined. Sometimes the focus may be along several parallel, radial or intersecting lines.

The main shock of earthquakes is preceded by preliminary tremors. These are again divided into two groups— (1) *Primary*, *Push* or P-*waves* which are longitudinal and compressional in nature and are similar to those of sound waves in which the movement is to and fro in the lines of propagation, and (2) *Secondary*, *Shake* or S-*waves* which are transverse and distortional in nature and are similar to those of light waves in which the movement is at right angles to the lines of propagation. These preliminary waves are followed by the main shock. The main shocks travel near the surface region whereas the P and S waves can pass through solids. (3) The main waves are called the *Free*, *Long* or L-waves. They are also known as the *ground* waves or the *Raleigh* waves. The L waves follow a circumferential path whereas the P and S waves proceed towards the centre. The peculiarity of the P and S waves is that they are subject to optical laws of reflection and refraction. If the earth would have been homogeneous, the P and S waves would have been straight lines. Gradual increase in density with depth will cause a concave path for the P and S waves. After the main waves have died down (4) *after shocks* are felt (PL—33.)

The record of Croatian earthquake (in the Kulpa Valley in Jugoslavia) on December 8, 1902 shows two other P and S waves besides the normal P and S pair. This new pair has been designated by the letters Pg and Sg. They are similar to ordinary P and S waves but they have slower rate of travel.

The Tauern earthquake of Austria on November 23, 1923 shows another new pair of P and S waves. These have been designated as P* and S* waves in seismological literature. They are also similar in nature to ordinary P and S waves but have intermediate velocity between P-S and Pg-Sg pairs. At a distance of 500 miles from the surface all the pairs travel with equal velocity.

The facts are best explained by the assumption that there are three distinct layers in the outer region of the earth. The ordinary P and S waves have travelled through the lowest layer which is believed to be consisting of dunite or peridotite rock material. The P* and S* waves have travelled through the intermediate layer, believed to be formed of basaltic or amphibolitic material, whereas the Pg and Sg waves have travelled through the outermost layer belived to be granitic in composition. These have been dealt in the chapter on the Interior of the Earth (Chapter—XVI).

The P-waves are the fastest and then come the S-waves and the L-waves last of all. The P-waves can be transmitted through solids as well as fluids but the S waves are obstructed by fluids. The L-waves are believed to be produced by the P and S waves. They produce the greatest damage on the surface.

Intensity of Earthquakes—The conception of isoseismal lines demands a scale of reference to measure the intensity of earthquake waves at different places on the earth's surface. The intensity is measured by the effect of an earthquake on a seismograph, by the sensation of people and by the damage to buildings and ground. The first one to be introduced is that by an Italian seismologist Rossi and Forel, a Professor at Geneva. It has got ten divisions as shown on the next page.

Intensity	*Name of the shock*	*Effects*
I.	*Microseismic*	Recorded by delicate instruments only.
II.	*Extremely Feeble*	Recorded by all seismographs. Felt by experienced persons only.
III.	*Very Feeble*	Felt by several persons at rest.
IV.	*Feeble*	Felt by persons in motion. Affects windows and ceilings of houses.
V.	*Moderate*	Felt by every one. Greater disturbance on houses and produces ringing of bells.
VI.	*Fairly Strong*	General awakening of persons from sleep and ringing of bells. Clocks stop. Trees oscillate.
VII.	*Strong*	Overthrows movable objects. Causes removal of plasters but no general damage to building. Church bell rings.
VIII.	*Very Strong*	Fall of chimneys and cracks in the walls of buildings.
IX	*Extremely Strong*	Partial or complete destruction of buildings.
X.	*Shock of Extreme Intensity*	General destruction of buildings and ground. Produces landslides in mountainous regions.

Mercalli, an Italian seismologist, put forward another scale. It had at first ten divisions but later the number of divisions was made twelve. This is as follows. (The acceleration produced measures the intensity of vibration. The acceleration due to gravity in this scale would be 980 cm/sec/sec).

Intensity	*Acceleration produced*	*Name of the Shock*	*Effects*
I.	Less than 1 cm/sec/sec	*Instrumental*	Recorded by seismographs only.
II.	Over 1 cm/sec/sec	*Very Feeble*	Perceived only by sensitive persons.
III.	Over 2·5 cm/sec/sec	*Feeble*	Perceived by persons at rest.
IV.	Over 5 cm/sec/sec	*Moderate*	Perceived by persons in motion.
V.	Over 10 cm/sec/sec	*Fairly Strong*	Wakes persons. Rings bells.
VI.	Over 25 cm/sec/sec	*Strong*	Slight damage to buildings.
VII.	Over 50 cm/sec/sec	*Very Strong*	Produces cracks in the walls.
VIII.	Over 100 cm/sec/sec	*Destructive*	Throws chimneys.
IX.	Over 250 cm/sec/sec	*Ruinous*	Overthrows buildings.
X.	Over 500 cm/sec/sec	*Disastrous*	General destruction of buildings.
XI.	Over 750 cm/sec/sec	*Extremely Disastrous*	Few buildings are left standing. Causes fissures in the ground.
XII.	Over 980 cm/sec/sec	*Catastrophic*	Total destruction of buildings and ground. Objects thrown up.

Earthquake Recording Instruments or Seismographs—Primitive and crude methods for ascertaining the directions of earthquake waves were made from the wave directions of water, specially of coloured water. Later troughs full of mercury with grooves connected to tubes were devised, from which earthquake would overthrow mercury through the grooves into the tubes and from an observation of this the direction would by determined. Chand Heng of China, devised a method in 132 A.D. to record the earthquakes. This was the first of its kind. It had the figure of a frog at the centre of a vessel which was again surrounded by eight figures of dragons sitting on spring and each holding a ball in its mouth. When there was an earthquake the nearest dragon would throw the ball into the mouth of the frog and thus the direction of the earthquake waves would be determined. In more recent times the pendulum seismographs came into existence. It consists of a horizontal pendulum which records the earthquakes by means of a beam of light thrown on a piece of photographic paper by the reflecting mirror attached to the pendulum. The time is measured by dots at the end of each minute.

Seismograph or the distant earthquake recording instrument, in its present day form, consists of a stout pillar attached firmly to the floor of the observatory building. *Seismometers* record local shocks only. The pillar of the seismograph is connected by means of a wire to a cylindrical rod with a sharp point at its upper end. The sharp end moves between two bifurcations of a long pointer having a pencil point at the other end. The pencil point touches a rotating drum with paper fixed on its upper surface. When there is an earthquake the building is shaken and so the pillar is also shaken. Its pointed end therefore alternately strikes the bifurcated parts of the long pointer. The pencil point attached to the other end of the pointer record the oscillatory movement on the paper over the drum.

In later forms of seismographs instead of pencil point there is a mirror arrangement which throws a ray of light on the photographic paper on the rotating drum. The paper, on development, will show the record of the earthquake shocks. A chronograph, attached to the instrument, records the time of arrival of the shock.

The record left on the paper (ordinary or sensitised as the case may be) is known as the *seismogram.*

Earthquake belts or Seismic belts—Upon the surface of the earth there are a few more or less well defined areas where earthquakes are more frequent than in other areas. These areas are called *seismic belts.* One such seismic belt encircles the Pacific Ocean and is known as the Circum-Pacific belt. This is the most violently shaken area where 68 p.c. of the earthquakes occur. The other is the Mediterranean seismic belt which starts from the East Indies and passes through the Himalayan foot-hill region, Asia Minor and the Alps. Here only 21 p.c. originate. The rest 11 p.c. originate else-where. Roughly the seismic belts coincide with the volcanic belts of the world and more closely with the young mountain belts of the world. The rift valley region of the East and Central Africa is another minor seismic belt. Earthquakes are rare in the Atlantic region and in the interior of Europe including Britain but it should be remembered that no area is totally free from earthquakes.

Earthquakes are especially frequent where slope is steep specially on the outer side of a mountain or in steep coastal regions. Crustal disturbances produce such steep slopes and as crustal disturbances are also the cause of earthquakes, the seismic belts lie in areas with steep slopes.

Indian Earthquakes—(1) *The Assam Earthquake*—This is one of the most disastrous shock that has occurred ever on the surface of the earth. The research of R. D. Oldham (Mem. G.S.I. Vol. XXIX, 1899) has made it well known to the scientific world. This earthquake occurred on June 12, 1897. Rumbling sounds were heard two seconds earlier. The surface moved backward and forward like trees caught in a storm. Shillong and neighbouring areas of 150,000 square miles were almost destroyed within a minute.

The main shock lasted for one minute but the damage was done in first half of it. Fissures developed on the ground and through these fissures water overflowed and land slides occurred in huge quantity. The drainage system of the area was highly disturbed.

The earthquake originated from a fault zone more or less parallel to the Chidrang River. The horizontal vibration attained an amplitude of 7 inches and the velocity of the waves was according to Oldham 2 miles per sec. nearly. The ground vibrated more than 200 times a minute.

On August 15, 1950, at about 7-40 P.M. Assam, particularly the north-eastern part of it was rocked by another tectonic earthquake of great intensity. At Shillong, three shocks were felt. The first lasted for five minutes, the second and the third for one minute each. Seismographs at Calcutta and Poona were thrown out of order. It was more severe than the North Bihar and Baluchistan (Quetta) earthquakes. The epicentre was located at latitude 29°N and longitude 97°E, near the Lohit River. The shock devasted an aera of 5000 sq. miles (excluding the northern hilly region). Dibrugarh, North Lakhimpur, Sibsagar, Jorhat, Pasighat and Tinsukia were affected severely. Railway lines were dislocated, bridges (as the Ranganadi bridge) damaged and roads fissured. Landslides blocking river courses (as in the cases of Subansiri, Lohit etc.) occurred resulting, at a later period floods by the removal of the rock debris.

(2) *The North Bihar Earthquake*—It occurred on Jan. 15, 1934 at about 3 P. M. The northern part of Bihar and Southern Nepal were shaken by a severe earthquake. The worst affected areas were Motihari, Katmundu and Monghyr. Numerous cracks were developed and water overflowed through these. More than 12,000 people were killed. The cause is believed to be due to some displacement below the alluvial plain at Motihari area. It has not produced so much geological effects as the Assam earthquake though it is highly destructive to human life (Vide Record, G.S.I. Vol. LXVIII, Pt. 2).

(3) *The Quetta (in Pakistan) Earthquake*—This occurred on May 31, 1935, at night when nearly 20,000 persons were killed. The worst affected area was very small compared to the destruction and hence it is believed that the origin was shallow. The epicentral area was between Quetta and Kalat. It was only 68 miles in length and 16 miles in breadth. Cracks were numerous on the ground and so also the rock falls but other effects were not so much pronounced (Vide Dr. West's report in the Rec. G.S.I. Vol. LXIX—Pt. 2.)

The study of Indian earthquakes shows that in the Himalayan region, where the younger rocks come in contact with the older rocks, earthquakes are frequent. These areas are naturally very unstable and displacements are often caused to relieve the strain. In the syntaxial bends disastrous earthquakes have occurred. The valley floor of the Indo-Gangetic Plain may also be at times displaced owing to the superincumbent load of sediments. The North Bihar Earthquake in 1934 supports the idea.

Geological Effects of Earthquakes—Apart from the immediate destruction of life and property, earthquakes produce other geological effects. Due to the passage of surface waves fissures are produced and through these fissures water often overfloods the region. This water brings enormous quantity of sand and often produces sand-dikes in these fissures. Roads are fissured, railways are twisted, submarine cables are damaged and bridges fall off from the pillars. A marked change is effected on the drainage system of the area. Rivers change their courses. New springs appear. Old springs stop. sometimes discharge of springs is increased and sometimes it decreases. Rock slides occur in hilly region and bring down huge quantity of rock material and thus aid the mass wasting process. Grounds are tilted and changes of ground level are at times effected. Relative displacements of areas and increase in the height of hills are also at times effected by earthquakes.

Prevision of Earthquakes—Earthquakes cannot be prevented but their forecast, like weather forecast, can be of immense value in minimising the disastrous effects by keeping people alert against the consequences of subsequent earthquakes. Earthquakes generally occur all on a sudden and without any warning. Sometimes preliminary tremors or rumbling sounds are perceptible but these are very rare.

As already pointed out the cause of the earthquake is the relief of strain by the displacement of the strata. When the strain is accumulating, some effects like slight tilting of ground or small rockslides are often seen.

Prof. Reid suggests the construction of a number of piers at some distances perpendicular to visible or supposed direction of a fault and a careful and regular study of them is likely to give some idea of the accumulating strain which is to cause an earthquake at a later date.

The second method is due to Dr. Davison. He suggests the recording of shocks and the increase in seismic activity along a known fault zone.

Late Prof. H. C. Das Gupta suggested a careful study of rain and snow fall. In humid countries rain water and snow are the main transporting agents. Again great stresses are set up by the transfer of materials from one place to another according to the ideas of isostatic adjustment. Therefore there is a likelihood of existence of a relationship between the rain and snowfall on the one hand and the periodicity of earthquakes on the other. Prof. Knot also believed in the same way and the Japanese seismologist Prof. Omori had shown that there is a coincidence between the rain and snow fall, and earthquake frequency. The idea however stands on a debatable assumption that earthquakes are of shallow origin.

Construction of Buildings in Earthquake Areas—Near the epicentral area the damage is at its maximum. Fortunately the area has a small dimension generally. Outside this area a careful design and a scientific choice of building materials may save many a building from collapse. From the ancient time man has been thinking of this problem. The temple of

Diana at Ephesus near Smyrna, off Greece, was built on a marshy land to protect it from any damage by earthquakes.

The surface waves are the most destructive. The damage depends upon the rate of vibration of earthquakes and the oscillation period of buildings.

To bear the strain two opposite methods in construction have been followed. In one, the idea is to make the structure very light and thus make it able to absorb the shock. In another the idea is to make the structure very firm so that the shock can have no effect on the building. The foundation upon which a building stands has been made loose or firm according to the two different ideas. The former method has rather been proved to be unsuccessful. A loose foundation can absorb the vibration to some extent but the surface waves here are higher whereas in a firm foundation the vibration is greater but the surface waves are lower in amplitude.

Windows and doors make the walls less strong. Vertical rows of them are worse than diagonal rows. Low buildings can bear damage from errthquakes more than high ones and it is better to have a square foundation.

Of the building materials, a steel frame with reinforced concrete is the best and ordinary bricks are the worst as earthquake-resisting material.

CHAPTER XVI

INTERIOR OF THE EARTH

The interior of the earth is not approachable for direct observation. It has been possible for man to go 1·7 miles only inside the earth by digging and the deepest well that has been sunk for petroleum has gone not more than 3·9 miles inside the earth. Some of the shafts of the Kolar gold mines in Mysore have reached depths of more than 9000 ft. and are believed to be the deepest in the world. The deepest pipe for petroleum has reached a depth of 20,521 ft. in Wyoming.

These depths are so insignificant in comparison to the radius of the earth (which is nearly 4,000 miles) that no precise knowledge can be got from these diggings and borings. Scientists adopt indirect methods to get an idea of the interior of the earth.

Internal Heat—That the interior of the earth is intensely hot goes without saying. The more one goes down inside a mine, the more one experiences the gradual increase of temperature inside· Besides these, the internal heat is discernible from the many hot springs and volcanic eruptions in different parts of the earth. It has been noticed that for every 100 ft. of descent there is a rise of 1°C in temperature downwards from which the central heat comes to be 20,000°C nearly. But because of the relatively high concentration of radioactive elements near the crustal region, the temperature gradient or the rate of rise of temperature is probably higher in the upper part of the crust than it is downwards. It is believed that the core of the earth may have a temperature of nearly 6,000°C. This is the same as the temperature of the outer part of the solar disc out of which the earth originated.

Like temperature, pressure is also tremendous at the central part of the earth. It has been observed that at a depth of 1 mile, the pressure is 450 tons per square foot of area. From that it has been calculated that the core of the earth will receive a pressure of 2 million tons per square foot. As the value of the acceleration due to gravity decreases with depth, the value of the interior pressure is likely to be much less. Heat increases the volume of a substance, pressure diminishes it. Inside the earth these two opposite agents are working. Owing to the tremendous pressure and heat, materials inside the earth are likely to be pliable but it is not thought to be liquid.

Many places upon the surface of the earth are covered by sedimentary rocks. Below that there are igneous rocks, the sp. gr. of which varies from 2·75 to 3·1. But the density of the earth as a whole is 5·5. From this it it clear that the internal material of the earth must be very heavy with a sp. gr. as high as 7 or 8. Mere pressure cannot increase the sp. gr. to such an extent. Hence it is thought that the interior of the earth is made up of some heavy metallic elements. The meteorites are generally made up of nickel and iron compounds. They are also members of the same solar system. Hence from their composition it can be guessed that the interior of the earth is made up of nickel and iron. The response of the earth to magnetic forces also bears testimony to this idea as nickel and iron are two of the most highly magnetic substances.

The earth first assumed a liquid state and then it passed into the solid state. According to many, the earth is solid only on its upper surface, the interior is molten. They cite volcanic eruptions as evidence. The failure of the earth to respond to the attractive forces of the sun and the moon to produce tides upon the surface, discards the idea. Others hold that the crust and the centre are solid and the intervening part is liquid. Some others think the intermediate part between the centre and the crust to be gaseous. Definite opinion on this subject requires precise observation of the effect of pressure and heat in the interior of the earth. Direct observations being impossible, help of indirect methods is generally sought for.

Now-a-days a fair idea of the interior of the earth has been obtained from the study of the propagation of seismic waves through the earth. Originating from a volcanic eruption or more probably from an underground dislocation of rocks, an earthquake starts in the form of waves in all directions just as a surface of water disturbed by a stone, produces waves starting from the place where the stone falls on the surface of water. These waves are recorded by seismographs.

Generally speaking there are three types of earthquake waves--the P, S and L waves. Of these the normal P and S waves can pass through solids. The L-waves pass through the circumferential area of solids. From the study of earthquakes of different areas, two more sets of P and S waves have been detected. Of these two sets one set has a velocity less than that of normal P-S set. The velocity of the other is intermediate between that of this set and the normal set (Chapter XV—Earthquakes).

Three layers with different density have been thought out to account for the three sets of P and S waves. It has been thought that the slowest P—S set has gone through the outer layer of the lightest material; the one with intermediate velocity has gone through the intermediate layer with intermediate density and the normal P-S—set has gone through the lower layer of still heavier material. These layers are made up of progressively denser materials.

Lower layers are compressed by the pressure of the superincumbent layers and hence the material composing the lower layer becomes heavier. It has been conjectured that the three above mentioned layers are composed of granite (upper layer) basalt or basalt glass or amphibolite (intermediate layer) and dunite or peridotite (lower layer) successively. Their successive thickness is believed to be 6, 12 and 18 miles respectively. These three layers constitute the upper silicate layer.

The L-waves while passing through ocean-floors acquire more velocity than while passing through continental land masses. This shows that the material (granite) with which land masses are generally composed is practically absent on the ocean bottom. The L-waves generally take a circumferential path round the earth and hence they cannot tell much about the interior. It is with the help of P and S-waves that a fair idea of the interior of the earth can be obtained. These waves behave like light waves and as the light waves are reflected and refracted by lenses, so these P and S-waves are reflected and refracted. The areas of heavier rocks act like lenses in the latter case.

The velocity of P and S-waves goes on increasing up to a depth of 1800 miles. Pressure effect is the cause. Below 1800 miles the rate of increment diminishes. Below 600 miles the diminishing is noticeable. From that it is thought that materials below 600 miles are quite different from the materials above it. The centre fails to transmit S-waves and the P-waves become extremely faint. It is therefore believed to be in liquid state but Gutenburg claims to have detected S-waves passing through the centre. The centre is believed to be made up of nickel and iron and is therefore called *nife.*

The following is an arrangement of the layers of the interior of the earth. This is according to Vander Gracht, Gutenburg and others.

(1) *Outer silicate layer*—This layer contains compounds of the elements O, Si, Al, K, Na and a little of Fe and Mg. Density 2·75—3·1. Thickness 36 miles. This layer is again sub-divided into three sub-layers.

(a) *Outer sub-layer*—It consists of granitic type of rocks. Density 2·75 nearly. Thickness 6 miles nearly.

(b) *Intermediate sub-layer*—It consists of basaltic or amphibolitic type of rocks. Density 2·9. Thickness—12 miles nearly.

(c) *Inner sub-layer*—It consists of dunite or peridotite type of rocks. Density 3·1. Thickness 18 miles.

(2) *Inner silicate layer*—This layer contains compounds of O, Si, Mg, Fe and Ca, K and Na rare. Density 3·10 to 4·75. Thickness—700 miles nearly.

(3) *Pallasite layer*—(Pallasite is a compound of Ni and Fe)—This layer contains compounds of O, Si, Mg, Fe, and metallic Ni and Fe. Ca, Al, K and Na are absent. Density from 4·75 to 5·0. Thickness—1100 miles nearly.

(5) *Core or Nife*—It consists of metallic Ni and Fe. Density 11·0. Thickness 2200 miles.

V.M. Goldsmidt from an analogy with the extraction of Fe and Cu has depicted the interior of the earth in a slightly different way. During the extraction of Iron and Copper from their ores, a layer of oxide and sulphide forms above the metallic layer. Goldsmidt likewise conceived such an oxide and sulphide layer above the metallic Ni and Fe core. According to Goldsmidt the layers are arranged as below.

(1) *Outer layer*—Density 2·8. Thickness 75 miles nearly.

(2) *Eclogite layer*—Density 3·6 to 4·0. Thickness 650 miles nearly.

(3) *Oxide-Sulphide layer*—Density 5 to 6. Thickness 1100 miles nearly.

(4) *Core*—Density 8 to 11.5. Thickness–2200 miles nearly.

Thus inside the earth there seems to be a density stratification i.e. arrangement of materials according to density, the heavier being at greater depth. If we remember that the earth passed into the liquid state from the gaseous state and to the solid state from the liquid state this seems to be quite in keeping with our expectation.

Crust—It is the outer part of the earth which possesses high strength and rigidity. It is also called the *lithosphere*. Below the crust lies the substratum which is very weak and vitreous.

Sial—The upper most sub-layer in the crust of the earth is called the sial (from silicon and aluminium). It contains the lightest materials (granitic) of density 2·75 nearly. Na, K, Al, Si and O with a little of Mg and Fe are present in it.

Sima—Below the sial layer comes the layer of sima named from silicon and magnesium. It contains basaltic, amphibolitic, dunitic or peridotitic materials which are quite heavy. Density varies from 2.9 to 3.1.

The three sub-layers in the outer silicate layer, already referred to, can be arranged thus :

Sial—	Upper sub-layer	Crust
Sima—	Intermediate sub-layer	
	Lower sub-layer	Substratum

Nife—The core or the central part of the earth which is believed to contain metallic nickel and iron (ferrum) is called nife. Density of the nife is 8 to 11·5.

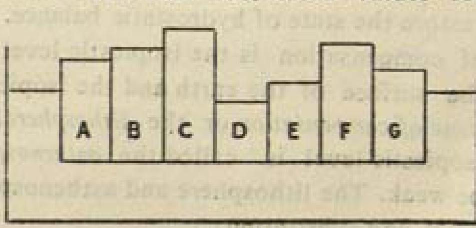
CHAPTER XVII

SOME WORKING HYPOTHESES

1 Isostasy—The word Isostasy has come from the Greek word *Isostasios* meaning "in equipoise". It was first used by the American geologist Dutton in 1889 (though ideas of isostatic adjustment were already thought of) to denote the equilibrium existing between the elevated masses and the depressed basins and a tendency of these elevated masses and the depressed basins to reach a sort of hydrostaic balance. Dutton suggested that the elevated masses are characterised by rocks of low density and the depressed basins are characterised by rocks of higher density. Accordingly a level is thought to exist where the pressure due to the elevated masses and depressed areas would be equal. This is called the *isopiestic level* or the level of uniform pressure. It is imagined that on unit area on this level the pressure due to the overlying masses is the same every where, whatever may be the height of the columns or whatever may be their surface relief. It is clear that higher columns will have low density and lower columns will have high density materials so that the weight of these two columns on the isopiestic level may be the same. Any loading due to sedimentation, deposition of ice and intrusion of igneous matter, or unloading due to denudation and melting of ice, of the columns will therefore disturb the balance and compensation in the form of depression or elevation will follow to restore the state of hydrostatic balance. The maximum depth of compensation is the isopiestic level and the zone between the surface of the earth and the isopiestic level is called the *zone of compensation* or the *lithosphere*. The zone below the isopiestic level is called the *asthenosphere* which is held to be weak. The lithosphere and asthenosphere are equivalent to crust and substratum.

Development of the idea of isostasy has been due much to the work of geodesists who use two important methods of investigation (i) deflection of the pendulum from the true vertical direction at mountain stations due to the attraction of the upstanding masses and (ii) gravity measurement.

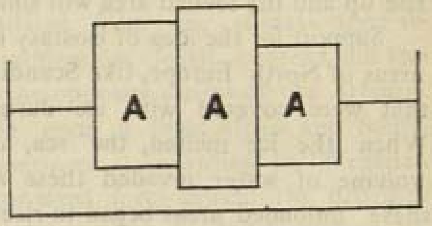
A pendulum bob suspended near an upstanding mass will be attracted laterally towards the mountain and will deflect from the true vertical direction. From the assumption that the average density of the rock on the surface and below the upstanding mass is the same and knowing the volume of the upstanding mass, the lateral attraction can be calculated. This calculated value is then compared with the observed value after reducing both to the surface of an ideal globe. Actually it is found that the deflection of the pendulum bob from the vertical is only a fraction of the calculated value. The difference between the calculated value and observed value, in the case of pendulum deflection, is called the *unexplained residue*. During the survey of the low lands south of the Himalayas the deflection of the pendulum from the true vertical due to the attraction of the visible masses of the Himalayas and Tibet was calculated to be 15″·885 seconds of arc and found to be 5″·328 seconds of arc. The explanation is that the rock below the upstanding masses is light i.e. composed of low density materials or there is a deficiency of mass. This explanation is further supported by gravity measurement. This oscillation of pendulum is governed by the intensity of gravity which varies with altitude, latitude, etc. By considering these factors the value of gravity can be calculated. It is observed that the calculated values for mountain stations are higher than the observed values. The difference between the calculated value and the observed value, in the case of gravity measurement is called *anomaly*. The



Fig—57
Isostatic balance

explanation is the same as before, namely that there is a deficiency of mass in the upstanding columns of mountain masses. Similarly it is thought that there is an excess of mass in the rocks of low lands or depressed basins.

In fig. 57 all the blocks have the same weight and cross-section. Hence they will sink to the same depth in a suitable liquid medium. Their lengths will vary inversely as their densities and the upper surfaces will be irregular. The longer blocks may be taken to represent mountains and lower blocks ocean basins. This figure illustrates the principle of hydrostatic balance.



Fig—58
Isostatic balance

In fig. 58 all the blocks are made up of the same material but they are of different heights. Hence they will sink to different depths in a liquid medium and irregularties will be both on the surface as well as below. Seismological, geophysical and geological considerations point to the possibility of the second kind of arrangement and balance.

If a portion is cut from any block in any figure and placed on the other, equilibrium is disturbed and restoration of equilibrium is effected by the rising of the unloaded part and sinking of the loaded part. Causes of loading and unloading have been already stated.

The equilibrium is again restored by the flow of mobile asthenospheric material at depth as a consequence of which the loaded block sink and lighter adjoining blocks rise upwards. Immediate and perfect adjustment is however not possible. This is because of the strength and resistance of the lithosphere and viscosity of the asthenosphere.

When a mountain mass or an elevated plateau is undergoing denudation, the sediments are taken and deposited in an adjacent low-lying tract. Hence with denudation the mountain or the plateau becomes lighter as a result of loss of material and the low-lying tract, where the deposition is going on, becomes heavier as a result of sedimentation. Hence the pre-existing equilibrium between the elevated and depressed areas is disturbed and to restore it the unloaded area will rise up and the loaded area will sink down.

Support for the idea of isostasy is obtained from the rise of areas of North Europe, like Scandinavia, and North America that were covered with ice during Pleistocene glaciation. When the ice melted, the sea, as a result of the increased volume of water invaded these areas. After sometimes these unloaded areas began to rise up and as a result the sea began to recede, proving thereby the principles of isostasy.

2 **Continental Drift**—There are three persons who assume the drifting of sial blocks over the simatic layer as a result of which the present configuratian of the earth with its mountains, continents and oceans was reached. They are Taylor, Wegener and Daly.

Taylor assumed the drifting of the continental blocks towards the equator to explain the formation of the Tertiary mountains. He cites the tidal forces of the sun and the moon as a cause for it. Taylor says that the moon was captured by the earth in late Cretaceous time which increassd the tidal forces from that time. The earlier mountains, he thought, to be result of the attractive forces of the sun when the earth was, in his opinion, nearer the sun. The Middle Carboniferous glaciation however goes against the idea.

Alfred Wegener, another propounder of the drifting of continents, was a German meteorologist. In his research to determine the climates of the past he noticed that there are such places on the surface of the earth where the present climate does not tally with that of the past. There are some places where once there was cold climate but now it is having hot climate. This might have been caused in two ways—either the climate has changed or the position of the place has been altered. To imagine the change of climate it requires the assumption of many changes like that of solar radiation, the inclination of the earth's axis etc., which are not acceptable. So only the change of position of the place is left to explain the change of climate or, in other words, the continental parts have drifted from one climatic zone to another. Similarity in stratification, fossil content and the strike of the mountains on the opposite shores of the Atlantic Ocean suggests that once upon a time Africa and South America formed a single continent. According to Wegener an west-ward and an equator-ward force caused the drifting. The equator-ward force was responsible for the formation of the Alpine-Himalayan chain of mountains and the west-ward force was responsible for the formation of the Rockies and the Andes. As a cause Wegener cited tidal forces for the equator-ward drift and centrifugal force resulting from the difference in altitudes of the centres of gravity of the sial and simatic layers. According to Wegener in early Palaeozoic time the continents were grouped together to form one great continent which he called *Pangaea*. It was surrounded by a vast ocean called *Panthalassa*. This Pangaea was afterwards broken to pieces and then the parts of it drifted to form the present continental units. The drifting probably began in Silurian and continues even to-day. These separated parts of the continental units very nicely fit if put close together just like the teeth of two saws (c.f. the opposite shores of the Atlantic Ocean). The poles of the earth also migrated from place to place in the past.

One of the merits of this hypothesis is that it explains the mountain-building phenomenon nicely. Wegener believes in the isostatic equilibrium in the earth's crust. Wegener's idea of continental drifting can nicely explain—(i) variation of climate in the past, (ii) occurrence of identical fossils in separated parts of the earth, (iii) identical geological structures in separated parts of the earth and (iv) mountain-building.

Like Wegener *Daly* also accepts the initial united continent Pangaea, from which the present continental units drifted over the substratum which is elastic and viscous thereby producing the present oceans and continents. As a cause he advocates the forces of *gravitation*.

The other hypotheses like the *Radio-activity and the Thermal Cycle of Joly*, the idea of *Convection Currents in the Sub-crustal Region by Holmes* and the idea of *Contraction of the Earth due to Secular Cooling* have been discussed in the chapter on the mountains and their origin.

INDEX

PREFACE TO THE FIRST EDITION

This book is a little venture to remedy in part the difficulties which the Indian students preparing for University Examinations in Geology encounter. As a student and later as a college teacher I have constantly experienced great difficulties caused by the absence of any book on this subject suitable for Indian students. Most of the books on the subject are foreign, dealing with structures and features existing in foreign lands and scarcely there is any space for their Indian counterparts or any reference to these. Moreover these books being very costly are beyond the reach of average Indian students. My object in this book has been to describe and cite Indian examples as far as possible apart from describing the general principles involved in this branch of Geology and secondly to present these in a cheap volume. How far I have succeeded in this venture particularly with regard to the first idea, upon which the merit of the book will depend to a large extent, will be judged by the reception that it gets from those for whom it is written as well as from those interested in the teaching of Physical Geology of India.

* * * *

I am indebted to the Director, Geological Survey of India, for kindly supplying photographs for illustration and permitting the same to be printed in this book. My thanks are also due to my revered teachers, Prof. S. K. Roy and Prof. S. N. Mukherjee of the Presidency College, Calcutta, for kindly revising the manuscript and giving valuable suggestions for its improvement. I am also indebted to my students Sri D.K. Sen Gupta, Sri D.R. Budhia and Sri S.P. Gupta for helping me in various ways... ... .

* * * *

St. Xavier's College,
Ranchi.
1st. July, 1950.

A. K. DATTA

PREFACE TO THE SECOND EDITION

The exhaustion of the copies of the First Edition of this book necessitated the publication of the Second Edition which has been thoroughly revised and considerably enlarged giving more and later informations.

I am indebted to each and every teacher of Geology in the different Colleges and Universities of India. But for their kind help this book would not have been so well received. I tender my heartiest thanks to them. It is my duty to express my gratitude in particular to Dr. S.C. Chatterjee (Patna), Dr. C. Mahadevan (Waltair), Prof. N.N. Chatterjee (Calcutta), Dr. Rajnath (Banaras), Prof. N.L. Sharma (Dhanbad), Dr. A.S. Kalapesi (Bombay), Prof. P.N. Mukherjee (Calcutta), Dr. S. Deb (Calcutta), Dr. R.C. Misra (Lucknow), Prof. T.N. Muthuswamy (Madras), Dr. K.P. Rode (Udaipur), Prof. L. Rama Rao (Bangalore), Prof. S. Roy (Calcutta), Prof. P. Dutta (Calcutta), Dr. S.N. Wakhalloo (Patna), Prof. S. Mukherjee (Calcutta), Dr. M.L. Misra (Banaras), Dr. G. Chiplonkar (Saugor), Prof. K. V. Kelkar (Poona), Prof. Muzafer Ahmed (Aligarh), Prof. G. Subba Rao (Jabbalpore), Prof. K. Sripada Rao Kilpady (Nagpur), Prof. N.K. Mukherjee (Banaras), Prof. R. Sawney (Jammu), Prof. S. Mukherjee (Ahmedabad), Prof. Habibur Rasul (Aligarh), Prof. K. C. Dubey (Saugor), Prof. N. C. Mithal (Jammu), Prof A. P. Jain (Patna), Prof. G. P. Srivastava (Ranchi), Prof. R. Verma (Ranchi), Prof. Umesh Chandra (Ranchi), Prof. Bholanath (Patna) and Prof. D. N. Ojha (Patna).

*   *   *   *

St. Xavier's College,
Ranchi.
1st. June, 1957.

A. K. DATTA

PREFACE TO THE THIRD EDITION

The quick exhaustion of the Second Edition of the book, although comparatively of a small number of copies, speaks of its popularity which is due to the kind help of all Professors of Geology of the different Indian Colleges and Universites. I have received all help from the Professors whose names have been gratefully mentioned in the preface to the Second Edition and also from Dr. M.S. Krishnan (Director, Indian School of Mines and Applied Geology, Dhanbad) Dr. P.G. Dowie (Madras), Professor D.K. Chakravarty (Banaras), Dr. A. K. Dey (Cuttack), Dr. T. C. Bagchi (Kharagpur), Dr. R. N. Sukeswala (Bombay), Dr. J. M. Chowdhury (Gauhati), Dr. M. Srirama Rao (Jabalpur), Dr. M.M. Chatterjee (Calcutta), Prof. M. R. Srinivasa Rao (Bangalore), Dr. N. Satpathy (Cuttack), Dr. N. Kanungo (Cuttack), Dr. P. Ganju (Aligarh), Prof. G.N. Mathur (Udaipur), Dr. L. V. Agashe (Poona), Prof. Y. K. Agarwal (Dhanbad), Prof. T. Narsingham (Dhanbad), Prof. S. Chatterjee (Calcutta), Prof. T.C. Sinha (Chaibassa), Prof. V.N. Singh (Patna), Prof. R.C. Misra (Patna), Dr. S. Sarkar (Kharagpur), Dr. R. C. Sinha (Banaras), Dr. R. L. Singh (Banaras), Dr. T. Bhattacharya (Jadavpur), Prof. B. Mukherjee (Jadabpur), Prof. P. N. Hore (Jadavpur), Prof. R. L. Mehta (Jammu & Kashmir), Prof. G. P. Dubey (Saugor), Professor Anantharaman (Mysore), Prof. C. Naidu (Bangalore). Prof. D. Neogi (Kharagpur), Prof. A. Roy (Calcutta), Prof. B. Ali (Aligarh), Prof. R. Acharya (Cuttack), Prof. D. K. Sen Gupta (Kharagpur) and Prof. D. K. Sen Gupta (Kharagpur).

I offer my thanks and express my gratitude to each one of them and to the Director, Geological Survey of India for kindly supplying me a few more illustrative photographs with the permission to print them in my book. I also thank my student Asif Asraf for giving me a few photographs for illustration.

The Third Edition has been further revised, enlarged and illustrated and I hope it will also be well received by the professors and students of Geology.

St. Xavier's College,
Ranchi
1st June, 1958.

A.K. DATTA

PREFACE TO THE FIFTH EDITION

We are thankful to all professors of Geology in different colleges of India for their kind appreciation of our book Introduction to Physical Geology. We express our greteful thanks to the professors whose names we are proud to mention in the preface to the earlier editions of the book and further to Prof : L. Suryanarayana (Vizianagram), Prof : N. Natarajan (Karaikudi), Prof : B. N. Das (Sundergarh), Prof: R. N. Misra (Sundergarh), Prof. N.K. Acharya (Cuttack), Prof. A. Prakash (Ranchi), Prof. Padmanavan (Dharamsala)., Prof. P. Misra (Dharamsala), Prof. N. P. Subramanyam (Guntur), Prof. P. Mahadev (Karikudi), Prof R.B. Bansode (Indore), Prof. S. Imam (Ranchi) and Prof. S.K. Bose (Calcutta).

We hope the new Edition will also be kindly received by the Professors as well as by the students of Geology in India.

Ranchi
1st. June, 1960

S.K. DATTA

Extracts of opinion of Professors of different Indian Universities on Introduction to Physical Geology by A.K. Datta.

I

1 *From* **Dr. S. C. Chatterjee, D.Sc., P.R.S. (Cal.), F.N.I., J.N.** Tata Professor of Geology, Patna Universiiy—

"I have great pleasure in writing a few words in appreciation of Prof. A.K. Datta's book "Introduction to Physical Geology". The book covers the syllabus in Physical Geology up to the degree standard. Its language is simple and the expression is lucid. Within as mall compass it deals adequately with all the fundamental principles of the subject. The most notable feature of the book which makes it indispensible to the Indian students is that it teems with typical landscapes and geomorphological features. I unhesitatingly recommend the book to our degree students..."

2 *From* **Dr. C. Mahadevan, M.A., D.Sc., F.A.Sc., F.N.I.,** Professor and Head of the Geology Department, Erskine College of Natural Science, Andhra University, Waltair—

"I have skipped through the book and find that it is drawn up excellently and its Indian example is a very special feature to commend itself as a suitable book for the B.Sc. students and for those taking Geology in Engineering and Agricultural courses......I congratulate you on the production of this book. The illustrations are indeed very good"

3 *From* **Dr. A. S. Kalapesi, D.Sc.,** Formerly Professor of Geology, St. Xavier's College, Bombay—

"It is a very interesting book well written with ample examples and illustrations from India. I appreciate your efforts to make it intelligent as well as useful to our Indian students. It is high time that we should have such books written by experienced teachers giving as much information from Indian standpoint of view. To a beginner or to one who takes interest in this subject, it is a simple and useful book as it gives a general idea of all the branches of Geology—specially a short account of minerals and rocks. Photographs and figures are well selected and clear and nicely printed. The diagrams are also well chosen and quite accurately done. The selection of the subject matter and its limitations are such as can be best decided by a teacher only and I think you have taken the correct and proper estimate and view from a student's standpoint. I congratulate you on producing such a book at a time when the subject is coming in front line"

4 *From* **Prof. P.N. Mukherjee**, M.Sc. (Lond.), D.I.C. (Lond.), M.M.G.I., Formerly Geologist, G.S.I. and Head of the Department of Geology, Ashutosh College, Calcutta—

"I read your book 'Introduction to Physical Geology' with great interest. We were surely very badly in need of such a book for a long time, as there is none like this for junior students. The most interesting feature of the book is the description of some of the Indian examples of Physical Geology so useful to the Indian students. This book would undoubtedly give great help to those preparing for the I.Sc. and B.Sc. examinations in Geology. I am sure there would be a great demand for such a book."

5 *From* **Dr. K.P. Rode**, M.Sc., Ph.D. (Zurich), University Department of Geology, University of Rajasthan, Udaipur—

"I congratulate you heartily on the attempt you have made in writing this book on Indian Physical Geology wherein our students, both of Geology and Geography can now read with lively interest as you have given all Indian examples"

6 *From* **Prof. T.N. Muthuswamy**, M.A,, F.A.Sc., Professor of Geology, Presidency College, Madras—

"I went through the book and think it very useful to B.Sc. students"

7 *From* **Dr. R.C. Misra**, Ph.D., F.G.M.S., Geology Department, Lucknow University—

"I congratulate you on this attempt which was long overdue from Indian teachers"

8 *From* **Dr. G.W. Chiplonkar**, D.Sc., Department of Geology, University of Saugor—

"A book on this subject to meet the requirements of Indian students was very much needed and I am glad that you come forth with a book of that kind, on doing which kindly accept my congratulations"

9 *From* **'Science and Culture'**, October 1950—

"Students interested in the science of the earth in this country, would very much welcome books of this nature, which deal principally with all the forces of Dynamical Geology that shape the face of the earth.

... ...

The book would thus be useful to the students of the Intermediate science classes and also to B.Sc. pass course students of the Indian University. Non-geologists who are interested to know about the natural phenomena such as earthquakes, volcanoes, glacier etc. of this country would also be very much benefitted by this book"

1 *From* **Dr. M. S. Krishnan**, Formerly Director Geological Survey of India and Director, Indian School of Mines and Applied Geology, Dhanbad :
"It is a good attempt to present the subject to the junior classes with examples taken from India".

2 *From* **Dr. P. C. Dowie**, Chief Professor, Department of Geology, Presidency College Madras :
"Introduction to Physical Geology by Professor A. K. Datta is an excellent book on Elementary Physical Geology for University students. The author has presented clearly and in simple language the fundamentals of the subject with Indian examples wherever possible. I have no hesitation in recommending it for the First Year B.Sc. students in Geology. It is also reasonably priced so as to be within the reach of students of average means".

3 *From* **Dr. T. C. Bagchi**, Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur :
"I have gone through your book Introduction to Physical Geology. I appreciate very much your effort for the production of a book on Physical Geology with Indian examples. The book has met the long felt need of Indian students and I congratulate you on the attempt".

4 *From* **Dr. R. N. Sukeswala**, Head of the Department of Geology and Geography, St. Xavier's College, Bombay :
"I have looked into your book. I find that it is a book written well in simple language covering the important topics for the students of Physical Geology. It is gratifying to note that the general get up of the book is what would have been desired.

Your attempt to quote Indian examples wherever possible is pariseworty".

5 *From* **Dr. J.M. Chowdhury**, Head of the Department of Geology, Gauhati University :
"We have recommended the book to the B.Sc. Students. It has been found to be very useful and illustrative and as most of the examples are from Indian localities, the students will also find the book quite interesting".

6 *From* **Dr. M. Srirama Rao**, Professor of Geology and Head of the Department, Mahakoshal Mahavidyalaya, Jabalpur :
"I have gone through your book Introduction to Physical Geology and find it interesting and nicely illustrated. I congratulate you on bringing out such a work that fills the need of the graduate students of India".

7 *From* **Prof. M. R. Srinivasa Rao**, Central College, Bangalore : "I have received your book Introduction to Physical Geology and I have no hesitation in saying that it is an ideal text book for the I. Sc. and B. Sc. students".

1 From Dr. M. S. Krishnan, Formerly Director, Geological Survey of India and Director, Indian School of Mines and Applied Geology, Dhanbad:
"It is a good attempt at presenting [illegible] the subject to the [illegible] classes with examples taken from India".

2 From Dr. [illegible], Chief Professor, Department of Geology, Presidency College, Madras:
"Introduction to Physical Geology by Dr. [illegible] is an [illegible] elementary [illegible] for the University students. The author [illegible] and in simple language the fundamentals of [illegible] with Indian examples [illegible] is recommended [illegible] of Physical Geology. It is [illegible] the needs of students of [illegible]".

3 From Dr. [illegible], Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur:
"I have gone through your book Introduction to Physical Geology. I appreciate [illegible] the need for the production of a book on Physical Geology with Indian examples. The book has met the long-felt need of Indian students and I congratulate you on this attempt".

4 From Dr. R. S. [illegible]wala, Head of the Department of Geology and Geography, M. [illegible] College, Bombay:
"I have looked into your book. I find that it is written well in simple language covering the [illegible] for the students of Physical Geology. It is [illegible] to note that the [illegible] of the book is what would have been expected.
Your attempt to quote Indian examples [illegible] is noteworthy".

5 From Dr. J. M. Choudhary, Head of the Department of Geology, Gauhati University:
"We have recommended the book to the B.Sc. Students. It has been found to be very [illegible] and illustrative and [illegible] of the examples from Indian localities [illegible] makes the book quite interesting".

6 From Dr. M. [illegible] Rao, Professor of Geology and Head of the Department, Maharaja's [illegible] Mahavidyalaya, [illegible]:
"I have gone through your book Introduction to Physical Geology and find it interesting and nicely illustrated. [illegible] in bringing out such a work that fills the need of the graduate students of India".

7 From Prof. M. B. Srinivasa Rao, Central College, Bangalore:
"I have received your book Introduction to Physical Geology and I have no hesitation in saying that it is an ideal text book for the I. Sc. and B. Sc. students".

CONTENTS

INTRODUCTION
TO
PHYSICAL GEOLOGY

CHAPTER I

INTRODUCTORY

Geology defined

The word *Geology* has been derived from the Greek words *Ge* meaning the *earth* and *logos* meaning *discourse*. Geology is therefore the science of the earth.

Branches of Geology

The subject of Geology is divided into several branches which are as follows :—

(1) *Physical Geology*—It deals with the geological processes which bring about changes upon the earth's surface. This includes :—

   (a) *Structural or Tectonic Geology*—It deals with the different kinds of structures produced in the crust of the earth as a result of the tectonic movements of the earth's crust.

   (b) *Dynamical Geology*—This deals with the agencies, both inside and outside, which tend to bring about changes upon the earth's surface.

   (c) *Physiographical Geology or Geomorphology*—This deals with the surface features of the earth or its topography.

(2) *Mineralogy and Petrology*—They deal with minerals and rocks respectively. The study of minerals (Mineralogy) includes the study of mineral formation, mineral association, mineral analysis, the study

of crystals and their formation. Petrology includes the study of rocks, their formation, their association etc.

(3) *Historical Geology*—It deals with the chronological changes brought about on the surface of the earth. It includes the study of—(a) *Stratigraphy*—dealing with the succession of rock formation and (b) *Palaeontology*—dealing with the relics of ancient animals and plants called fossils. (The word fossil has come from the Latin verb 'fodere' which means 'to dig'. So formerly the word fossil used to mean anything that was dug out. But then many minerals and rocks come under the usage of the term and hence later on the use of the term fossil was restricted to the organic remains preserved naturally. Hence fossils refer to the remains, or traces even, of animals and plants preserved in nature. These remains and traces are of the animals and plants which are mostly extinct now but some may have present-day descendants. The term also includes prehistoric finds of human activity.)

(4) *Economic Geology*—It deals with the utility of the study of geology and the practical application of the knowledge of geology.

Scope of Geology

A geologist is indispensable for the successful development of a mining industry. As a prospector and as an adviser for the fullest utilisation of an ore body, his advice is always sought. Not only in the field of mining and metallurgical industries, but also in the field of Engineering, geologists are to be consulted. Geologists help in the construction of dams, railway alignments, tunnels, construction of buildings in earthquake-shaken areas and in water prospecting including the selection of sites for water supply such as tube wells or ordinary wells. In problems of water supply, drainage and irrigation the advice of a geologist is indispensable.

Even in the field of public health he has much to contribute. In Europe the spas and other mineral springs which have been discovered by geologists and the waters of which have been tested by them, have been subsequently developed into health resorts. The waters of such spas have been largely used as remedy for the skin diseases, gout and rheumatism. Silicosis in miners has been traced by geologists to be due to their inhalation of minute particles of mineral matters. In the detection of adulteration of food matters by such mineral products as china clay and the like, and in the dust control of cities and towns, a geologist has much to contribute. In the analysis of drinking water and in the examination of water-bearing strata a geologist has a special field, as the excess or deficiency of any mineral matter in the drinking water is injurious to the human system. For instance, in an English town the calcium deficiency of children was found out by geologists to be due to the poor percentage of calcium in the drinking water which was again due to the low content of calcium in the water-bearing country rock of the place.

CHAPTER II

ORIGIN AND AGE OF THE EARTH

The earth being a member of the solar system, the origin of it is intimately connected with that of the solar system. There are many ideas to account for the origin of the solar system. Different scientists have tried to propound hypotheses on observation of the phenomena concerning the solar system and in their attempt to explain them.

Nebular Hypothesis by Kant

The earliest of the hypotheses for the origin of the universe is that of Immanuel Kant, the Prussian philosopher (in 1755). Newton has by that time propounded the Law of Gravitation. This Law has great influence on the hypothesis of Kant and later on that proposed by Laplace, the French mathematician (in 1796). According to Kant the solar system has evolved from a nebular mass. *Nebula* can be seen at night like white pieces of cloth in parts of the sky. They are mainly gaseous, though in places there may be clots of stars. Some of them are luminous and others are dark.

Kant proposed that the different parts of the nebula, out of which this solar system originated, at first moved in different directions at different speed. In course of time this nebula became a hot spinning one due to the concentration of the velocities in one definite direction. In its revolution through space this nebula began to radiate heat and as a consequence this gaseous nebula began to contract. This caused an increase in revolution and hence centrifugal force began to operate more and more. If any pliable sphere were revolved round its axis, its polar regions would get flattened and the equatorial region would be bulged and the sphere would assume an orange-like figure. This revolving gaseous nebula also assumed a similar figure. Gradual increase in the rate of revolution due to gradual contraction caused the separation of several rings from the equatorial region and these rings in time condensed to form planets. The planets, before solidification, would form satellites in the same manner. Such, in brief, is the history of the solar system as proposed by Kant. But Kant did not propose anything as to the ultimate origin of the nebular mass. This, he thought, was created in some supernatural ways.

Kant's hypothesis can not stand the attack of the Principle of Conservation of Angular Momentum which states, if no external forces are acting in a system the angular momentum remains the same and no interaction between the different parts can change its total amount of rotation. The idea, that rotation in a definite direction would be caused by the collision of the nebular matter, is unacceptable.

Nebular Hypothesis by Laplace

After Kant came Marquis de Laplace, the French mathematician. In 1796 he supported Kant's hypothesis after some modification. He assumed that the nebula was already a hot and rotating one. Then the history is much the same as that of the hypothesis of Kant. Thus he saved his hypothesis from the attack of the Principle of Conservation of Angular Momentum.

Laplace's hypothesis was able to explain that the planets are revolving round the sun in one plane nearly in their orbits. They are all rotating in the same direction from west to east. Almost all the satellites are also moving round the planets in the same way, and their orbits are slightly elliptical.

There is, however, one difficulty with this hypothesis. It is found that 98% of the total angular momentum of the entire solar system is distributed in the four major planets, although they contain less than 1/700 of the total mass, whereas the sun is contributing only 2% of the total angular momentum although it has over 99% of the total mass. If the outer part of the nebula had so much angular momentum, it could not have formed the solar system because condensation would not have been possible. So in the words of Spencer-Jones 'the origin of the solar system must be sought in the swift catastrophic action of the forces from outside.'

Planetesimal Hypothesis by Moulton and Chamberlin

After this Moulton in 1901 and Chamberlin in 1905 proposed the Planetesimal Hypothesis. They thought that the sun was wandering through space when a much larger star came so near the sun that little fragments were thrown off from the solar surface. The little fragments later aggregated to form planets and satellites. Hence these fragments are called planetesimals. The propounders thought that these planets were solid throughout but to Jeffreys they were first gaseous and then changed to liquid and finally to the solid state.

Jeffreys has shown that even if the existence of the solid planetesimals might be granted, they would soon go into the gaseous state by the heat generated by their mutual impacts.

Tidal Hypothesis by Jeans and Jeffreys

After this Jeans in 1919 and Jeffreys in 1929 propounded their Tidal Hypothesis. This hypothesis like the previous one assumes a biparental origin of the solar system. It states that a huge star while moving through space came near the sun and raised tides upon the sun just as the sun and the moon cause tides on the surface of the oceans. As the star drew nearer, a filament was thrown off from the sun which ultimately formed the planets. The planets under the attraction of other planets as well as that of the sun produced satellites of their own. In this way the whole solar system came into existence.

The modification of Jeffreys was an actual lateral impact with the sun and the invading star. It should be remembered that the idea of such an actual collision with the sun was first proposed by Buffon about two hundred years ago.

This hypothesis is reasonable and is now the prevailing one for the origin of the solar system. Though it has undergone some criticisms, it is able to explain most of the observed solar phenomena.

The distribution of angular momentum per unit mass of the invading star, the sun and the planetary system goes against the idea.

Double Star Hypothesis by Lyttleton

The Double Star Hypothesis was put forward by Lyttleton in 1938. According to his idea the sun, before the origin of the solar system, had a companion star at some distance. Later an invading star came very close to these double stars and captured the companion star of the sun and receded away. The filament drawn by the attraction of the invading star came into the control of the sun which later gave rise to the planets and satellites in much the same way as explained by the tidal hypothesis.

Weizacker's Hypothesis

The difficulties arising from the distribution of mass in the solar system as faced by the nebular hypothesis of Laplace were tried to be solved by Weizacker in 1943 by assuming that the original gaseous envelope round the sun was having a much larger quantity of hydrogen and helium which had dissipated into space in course of time. The materials that formed the planets were carried in floating condition as dust particles in the rotating gaseous envelope round the sun. When two such particles of equal mass collided with each other they broke to pieces but when a big particle collided with a smaller one the two united to form a bigger mass. This sort of aggregation led ultimately to the formation of planets.

Meteoric Hypothesis by Schmidt

Recently Dr. O. J. Schmidt has proposed a new idea known as the Meteoric Hypothesis. This idea depends upon the fact that at the central region of our galaxy there are some foggy matter which may be some meteoric matter. Schmidt proposes that during its passage near the centre of gravity of the galaxy, the sun attracted some such meteoric substance which began to revolve round the sun in one direction. Those particles, moving in the same direction would ultimately unite to form bigger planets and satellites in much the same way as what the planetesimal hypothesis proposes. Though this hypothesis is still in its experimental stage, yet it can explain well some of the observed phenomena relating to the solar system.

G. Kuiper's Hypothesis

In 1951 G. Kuiper tried in another way. His hypothesis states that the stars after their birth from the nebular mass, became in course of evolution, hot and rotating ones. At last due to the internal temperature and pressure majority of them broke to form double or triple stars. In the case of our sun conditions were such that it formed the nucleus of a rotating disc of cloudy matter, which with more and more rotation produced flattening and formed some whorls of matter under the action of gravity. These whorls collided and united to form bigger masses which were the planets. Smaller ones formed satellites.

Condensation of the Earth

After the formation, the earth, like all other planets, began to move round the sun in an elliptical orbit. While wandering through space, the earth began to cool by radiating heat. The outer surface being at lower temperature internal heat began to be transferred by means of conduction, convection as well as by gas emanation. As a result of continued cooling, the surface gases began to be changed into the liquid state. The first one to be cooled was that which had high vaporisation temperature. The liquid, thus formed being denser tended to go down but while sinking it came in contact with the increased temperature below as a result of which it was again vaporised. Hence it again came up and thus there was a transfer of central heat to the surface. Again there was the formation of liquid, again it sank down and again it was vaporised and came up. This process went on until there began the accumulation of liquid at the centre of the earth. Heat developed from various sources, like chemical changes, latent heat, radio-active disintegration etc. retarded the progress in cooling but ultimately the whole of the gaseous earth was transferred into a liquid state.

In the liquid state the materials were arranged according to their density and thus there developed a density stratification in the interior of the earth, with the heaviest at the centre and lightest on the top, near the surface. This is evident from the study of seismology (vide Chapter XVI Interior of the Earth).

Change from the Liquid to the Solid State

The loss of heat, by radiation, was going on from the surface of the earth and the outer liquid began to solidify. Being heavier the solidified material tended to sink down and by a repetition of the same process, the outer liquid layer became solidified. This retarded the transfer of internal heat, and differentiation into acidic, intermediate and basic type of rocks was effected. The lightest rock material accumulated at the top and within it the radio-active elements were also concentrated. The volatile constituents also tended to keep the material liquid. Hence change of liquid to the solid state of the earth was very slow. The outer crust became cystalline in due course and the substratum was vitreous. In this way the solidification of the earth was effected.

Origin of Continents and Oceans

The change of state of the earth from the gaseous to the liquid and from the liquid to the solid brought with it the contraction of the earth in volume as a consequence of which wrinkles were developed on the surface. When the earth was sufficiently cool to hold water, water-vapour of the atmosphere condensed to form water and this collected in the depressed portions of the earth's surface to form oceans. The outstanding portions remained as land.

According to Sollas the origin of continents and oceans is due to unequal pressure of the atmosphere on the earth's surface when it was in the liquid state. Chamberlin, the author of the Planetesimal Hypothesis, thinks that the earth's surface, formed by the accumulation of the planetesimals, would be low in some places and high in others forming the ocean basins and continental parts. Lapworth suggested the phenomenon of folding as the cause for the formation of land masses and ocean basins. The anticlines of such folds would correspond to the land masses and the synclines to the ocean basins. This idea has also been supported by Love from physico-mathematical consideration.

Lowthian Green presents a tetrahedral form for the earth

Fig 1

1 India. 2 Australia. 3 Antarctica. 4 Africa. 5 South America 6 Greenland. 7 North America. 8 Europe. 9 North Asia (according to Wegener's idea)

with faces corresponding to the ocean units. Though this has been supported by J. W. Gregory from geographical considerations, it has not been accepted as the tetrahedral form will change into a spherical form in the case of a rotating body.

According to Osmond Fisher the Pacific Ocean has been formed as a result of the detachment of the moon from the earth. It has not been accepted because the volume of the moon is much greater than that of the Pacific Ocean.

In whatever way they might have been originated, these small land portions later formed a vast continent called *Pangaea*. It was surrounded by a vast ocean called *Panthalassa*. The stratification of the crust and the fossils therein support the idea of such a continent. This continent later drifted to form the present continents and the water of the Panthalassa got into them to form the present oceans.

Two sets of opinion are current for the breaking up of the Pangaea. One is that the contraction due to condensation produced great rifts in the earth's crust and thus the Pangaea broke.

The other postulates the drifting of the parts of the Pangaea for the formation of the continents. The drifting of continents is largely due to the researches of Alfred Wegener. According to him, similarity in stratification, fossil content and the strike of the mountains on the opposite shores of the Atlantic Ocean suggests that once South Africa and South America were in one and the same continent. Further the western coast of South Africa and the eastern coast of South America more or less fit with each other supporting the view. According to Wegener a westward force and an equatorward force caused the drifting and the present configuration of the continents resulted in this way. The equatorward drift of Asia caused the formation of the Indian Ocean and the westward drift of the Americas produced the Atlantic Ocean.

Age of the Earth

The age of the earth has been tried to be determined from the evolutionary changes of animals, the rate of formation of stratified (sedimentary) rocks, the salinity of sea-water, the rate of cooling of the earth and the disintegration of radio-active elements.

Evidence from the evolutionary changes of animals—When the earth cooled down to be habitable, life appeared on it. The first formed animals were unicellular, i.e. composed of one cell. Later multicellular life with more complexities appeared in course of evolution. At first living beings were invertebrate, i.e. without any back-bone, and there were no hard parts in their bodies. For this reason they left no remains of their bodies to be preserved as fossils. Later animals with hard parts evolved and left remains to be preserved as fossils. The wonder of evolution is the appearance of man with brains. A rough estimate of the age of the earth can be made from the evolutionary development from unicellular organism to man. Biologists have determined the age of the earth to be 1,000 million years in this way. It is to be remembered that life appeared much after the origin of the earth and the age so determined is only a fraction of the real age of the earth.

Evidence from the rate of formation of sedimentary rocks—After the formation of the crust of the earth and the origin of continents and oceans, the denuding action on the land masses began by the agents like rain, wind etc. The sediment, thus formed, began to be collected on the ocean floors or in lake basins. This action is still to be seen at the mouth of the rivers like the Ganges, the Brahmaputra, the Nile etc. Uptill now nearly half a million feet of sedimentary rocks have been formed. Now if the annual rate of formation of these sedimentary rocks can be determined, the age of the earth can be calculated. The average rate of deposition of sediments and the total thickness of sedimentary beds have been taken to be one foot in 880 years and 5,14,000 ft. respectively, whence the age of the earth comes to be 400 million years. Metamorphic rocks formed from the most ancient sediments are 1,500 million years of age nearly.

Evidence from the salinity of sea water—Rivers bring with them a huge quantity of salts like sodium chloride, calcium chloride etc. in solution and pour them into sea. The sea water hence gets saline and the salinity increases every year. Now the total quantity of salt in the ocean can be determined from the total volume of the ocean water and the content of salt per unit volume, both of which can be determined. The yearly rate of increase of salinity can also be determined from direct observation and records. From these two data the age of the earth can be determined, at least from after the origin of oceans. From a determination of sodium and calcium salts in seawater the age of the earth has been determined to be 120 million years.

Evidence from the rate of cooling of the earth—From the rate of cooling of the earth Lord Kelvin determined the age of the earth to be between 20 to 400 million years. His determination of the age of the earth can not be accepted as he left out of consideration the radio-actively generated heat. Moreover the solar radiation of heat and the condition and ability of the sun to radiate heat might not have been the same always.

Evidence from the disintegration of radio-active elements—This is the most modern method of determining the age of the earth. There are certain elements like Uranium, Radium, Thorium etc. which spontaneously disintegrate rays and are changed to some other elements. Their final product is a variety of lead. Lead with atomic weight 206 is produced from Uranium, lead with atomic weight 208 is produced from Thorium and ordinary lead has an atomic weight of 207. Radium takes 1600 years to be half and Uranium takes a much longer period (4560 million years) to be so. Heat, pressure and chemical reaction have got no effect on their disintegration. From the determination of Uranium-Lead or Radium-Lead ratio in a rock body the age of the rock and hence, from it, the age of the earth can be determined. It is however to be borne in mind that no lead from other sources should come and mix with this radio-actively generated lead. This kind of determination has revealed that the most ancient rock on the earth (that containing Uraninite, from Huron Claim, Manitoba, Canada) is of the age of 1985 million years. As this rock occurs in a pegmatite cutting the country rocks, the invaded country rocks must be still older, probably over 2,000 million years. It is to be remembered that a great length of time elapsed before the formation of the rocks in the crust of the earth was possible. Hence from the above mentioned facts an imaginary estimate can be made about how old the earth is.

Stratigraphical Time Scale is shown in the following pages. Broad divisions of earth's history are called *eras*. Eras are divided successively into *periods* and *epochs*.

Eras	*Periods*	*Epochs*	*Notable physiographical events*	*Dominant animals*	*Dominant plants*	*Approximate age in million years*	*Climate*
1	2	3	4	5	6	7	8
Psychozoic (Reasoning life) or Quarternary. (*zoe* means life)		Holocene or Recent (with wholly) recent life)	Rise of civilization	Man	Modern Plants	0·015	Modern
		Pleistocene (with mostly) recent life	Periodic glaciation separated by warm interglacial period	Man	Modern Plants	1	Cold to glacial
Cenozoic (Modern life) or Tertiary. (*Cenos* means recent)	Neogene	Pliocene (with most recent life)	Rise of the Andes	Mammals & birds	Flowering Plants	10	Cold
		Miocene (with less recent life)	Rise of the Alps	Mammals & birds	Flowering Plants	30	Moderate
	Palaeogene	Oligocene (with few recent life)	Rise of the Pyrrenes	Mammals & birds	Flowering Plants	40	Warm to Moderate
		Eocene (dawn of recent life)	Rise of the Himalayas	Mammals	Flowering Plants	50	Moderate to warm

1	2	3	4	5	6	7	8
Mesozoic (Medieval life) or Secondary (*Mesos* means middle)	Late Mesozoic	Cretaceous (from creta meaning chalk)	Marine transgression in Trichinopoly	Dinosaurs	Elms, Oats, Mapples etc.	125	Moderate & humid
	Early Mesozoic	Jurassic (from the Jura Mts)	Marine transgression in Cutch	Dinosaurs	Conifers, Ginkgoes, & Horse-tails	150	Warm & arid
		Triassic (from the threefold division of rocks of this epoch in Germany into Bunter, Muschelkalk and Keuper)		Dinosaurs	Vegetation not abundant	180	Warm & arid
Palaeozoic (Old life) Primary	Late Palaeozoic	Permian (from Permia—an ancient kingdom near the Volga)	Major coal-bearing rock formation in India	Reptiles	Ferns	225	Moderate to glacial

1	2	3	4	5	6	7	8
		Carboniferous (from its coal formation)	Glaciation in the upper part in India.	Amphibeans	Ferns, Fern-like plants & club mosses	300	Glacial to warm at the end
	Middle Palaeozoic	Devonian (from Devonshire)		Fishes	Early land plants	350	Warm to Moderate
		Silurian (from Silures—an ancient tribe in Wales)		Fresh water fish and graptolites	Early land plants	375	Warm
	Early Palaeozoic	Ordovician (from Ordovices—an ancient tribe in Wales)		Grapto--lites	Algae	400	Moderate to warm
		Cambrian (from Cambria—the old name for Wales)	Rise of the Vindhya mountains in India.	Trilobites	Algae	500	Cold to Moderate

1	2	3	4	5	6	7	8
Proterozoic (early life)	Algonkian		Rise of the Aravalli mountains. Formation of Purana rocks—Cuddapah & Vindhyan deposits in India.	Protozoa		1,000	Cold at the end
Archaeozoic (Primitive life)			Formation of Dharwar rocks in India. Formation of Archaean rock system.	Age of larval life		1,500	
Eozoic (Dawn of life) (Eos means dawn)				Unicellular life			
Azoic (no life)			Initial development of the earth	No life			

CHAPTER III

COMMON MINERALS

Mineral defined

A *mineral* is a natural product formed by inorganic processes, which possesses a definite chemical composition and under favourable circumstances possesses a regular geometric shape which is an outward expression of its definite internal atomic structure. Artificial bodies produced in the laboratory are excluded from the list of the minerals. Though there must be a definite chemical formula there may be impurities and inclusions of foreign matter as well and amongst the members of a connected series there may be gradual transformation from one to the other in chemical composition, as in the case of plagioclase felspars.

Although a host of minerals are known in nature but practically a dozen covers the whole of mineral kingdom. These are the *rock-forming minerals* e.g. quartz, orthoclase etc. There is another class of minerals, which though negligible in relative abundance in the earth's crust, is very important from the economic point of view. They are *ore-forming minerals*. Suitable concentration of these minerals produces ore bodies out of which useful metals and other economic products are obtained, e.g. bauxite, chalcopyrite, hematite etc.

Identifying Characters of Minerals

Minerals may be identified by noting their physical properties as well as by chemical analysis and microscopic examination of them in thin slides. The physical properties inculde—(1) form, (2) cleavage, (3) fracture, (4) colour, (5) lustre, (6) streak (7) hardness and (8) specific gravity.

A mineral may also have any other special property peculiar to it only, e.g. magnetite is attracted by a magnet, galena marks paper etc. by which it can be identified. In the laboratory a mineral is examined in hand specimen by noting the above mentioned characters, while the examination under a microscope requires the preparation of a thin section. Minerals in microscopic sections show some characteristic properties and by noting them a mineral may also be identified. Mineral grains are also identified by microscopic study. Chemical analysis is also an aid to the purpose.

Form:—On the crystal development a mineral may show any one of the four forms—(a) Crystallised when showing well-formed big crystals. (b) Crystalline when showing smaller crystals not so well developed. (c) Crypto-crystalline when showing mere indistinct development of crystals which can be seen only from their thin sections under the microscope. (d) Amorphous—showing no crystal development at all.

Minerals may also show any one of the following descriptive forms :—

1 Granular—occuring in grains.
2 Friable—when the mineral mass breaks down by slight pressure.
3 Impalpable—When the grains are of extreme fineness.
4 Globular—showing an aggregate of small rounded masses.
5 Concretionary—showing an aggregate of bigger spherical bodies.
6 Nodular—when showing an aggregate of still bigger rounded bodies.
7 Pisolitic—when showing an aggregate of pea-like spherical masses.
8 Oolitic—when showing an aggregate of bodies resembling fish roe.
9 Botryoidal—when showing an aggregate of grape-like nodular masses.
10 Mammillary—when showing an aggregate of still bigger rounded masses.
11 Geoidal—when occuring as cavity-fillings.
12 Amygdaloidal—when occuring as almond-shaped cavity-fillings.
13 Nugget—when showing rounded bodies developed by rolling during transport.

14 Reniform—when showing kidney-shaped forms.
15 Lamellar—when showing thin leaf-like sheets.
16 Foliated, foliaceous or micaceous--when showing thin separable scale-like flakes.
17 Columnar or prismatic--when showing pillar-like masses.
18 Bladed—when showing an aggregate of masses resembling knife blades.
19 Fibrous—when showing an aggregte of fibres.
20 Acicular—when showing an aggregate of needle-like masses.
21 Capillary—when showing an aggregate of hair-like masses.
22 Filiform—when showingan aggregate of thread-like masses
23 Reticulated—net-like.
24 Stellated—star-like.
25 Dendritic—like the branches of a tree.
26 Tuberose—like the roots of a tree.
27 Radiating or divergent—branching from certain centre in more or less radius-like fashion.

Cleavage :—It is the property of easy fissility. Cleavage directions yield smooth surfaces on breaking. Cleavage may be termed—(a) perfect or distinct—when the broken surface is very smooth and fission is also very easy and, (b) imperfect or indistinct when the broken surface is not so smooth and fission is not so easy. If breaking is somewhat difficult and the broken surface is irregular then cleavage is absent. Non-crystalline minerals do not show any cleavage. Cleavage is also termed as cubic, rhombohedral, prismatic etc. according to the direction of breaking and shape of the broken piece.

Fracture :—The nature of the broken surface in any direction other than the cleavage direction will determine the fracture. It may be—(a) conchoidal when showing concave surface peculiar to conch shell, (b) uneven showing irregular surface, (c) even showing somewhat smooth surface, (d) hackly showing very much irregular surface, (e) splintery breaking in splinter-like parts.

Lustre :—It depends on the intensity of light reflection from the surface of the mineral specimen. Lustre of a mineral may be—(a) adamantine like that of a diamond, (b) resinous like that of resin, (c) pearly like that of a pearl, (d) metallic like that of a metal, (e) vitreous or glassy like that of glass, (f) silky like that of silk, (g) greasy like that of grease, (h) dull like that of earth. Other terms such as splendent, glistening, shining etc. qualifying the intensity of light reflection are also at times used in describing the lustre of a mineral.

Streak :—It is the colour of the powder of a mineral specimen left after rubbing it on a rough surface. Commonly mineral specimens are rubbed against unglazed porcelain plates. Generally streak shows the paler shade of the colour of the mineral although at times streak differs remarkably from the colour of the specimen.

Mohs' Hardness Scale

For testing the hardness of a mineral an arbitrary scale has been accepted which is called Mohs' scale of hardness (after the name of the propounder Mohs—a German mineralogist). In this scale there are ten minerals arranged in order of their increasing hardness and are marked serially from 1 to 10. The minerals are (1) Talc, (2) Gypsum, (3) Calcite, (4) Fluorite, (5) Apatite, (6) Orthoclase, (7) Quartz. (8) Topaz, (9) Corundum and (10) Diamond. Each mineral in the above scale will be scratched by all minerals with higher numbers.

Determination of the Hardness of a Mineral

Commonly a hardness box containing the above minerals (with the exception of diamond as it is very costly) is made and with the help of the minerals the relative hardness of an unknown mineral is determined by scratching the mineral to be tested with any mineral of the box. If a scratching is made on the mineral to be examined, the mineral is softer than the mineral of the hardness box. If on the other hand, the mineral of the hardness box is scratched then the hardness of the mineral (unknown) is greater than that of the mineral of the box.

Next the scratching is repeated with a mineral of greater or lower hardness, as is necessary, until no scratch is left on either of the two minerals. The hardness of the mineral is then equal to that of the box mineral. If any unknown mineral is scratched by any mineral of the hardness box, say 6, but is not scratched by the mineral 5, while the mineral 6, falls to power on the unknown mineral, then the hardness of the unknown mineral is intermediate between the two marks. In this way the hardness of a mineral is determined.

Precautions:—

(1) Fresh surfaces of minerals should be tried for hardness determination. Weathered surfaces give value less than the real one.

(2) Scratching should be done by the general surface of the specimens. Angular points or edges should be avoided.

(3) A real scratch mark should be distiguished from a chalk mark left by a softer mineral on a harder one. This can be done by blowing over the scratch mark or by gently rubbing it when a chalk mark will vanish but a scratch mark will persist and will present a groove cut on the mineral surface.

Specific Gravity

Specific gravity (Sp. gr.) of a substance is its relative density i.e., the ratio of the density of substance to the density of some standard substance. Commonly water is taken as the standard substance for the determination of the specific gravity of solids and liquids. The density of water at $4^{0}C$ (at which temperature water has the maximum density) is taken to be unit.

$$\text{Sp. gr.} = \frac{\text{weight of any volume of the substance}}{\text{weight of the same volume of water at } 4^{0}C}$$

We owe to the Greek scientist Archimedes for a ready method of determining the weight of the same volume of water as according to Archimedes a body completely or partially immersed in a liquid (or even a gas) apparently loses a part of its weight which is equal to the weight of the liquid displaced. A body when completely immersed in water will displace its own volume of water. Hence the apparent loss in weight of the body (i.e the weight of the body in air—the weight of the body when immersed in water) is equal to the weight of the same volume of water.

$$\therefore \text{Sp. gr.} = \frac{\text{weight of the substance in air}}{\text{weight of the substance in air—weight of the substance in water.}}$$

It is to be noted that although at the time of experiment, water is not likely to have the temperature of 4°C, but the difference in the value (from the real value) of the specific gravity obtained from water at the then room temperature is negligible.

There are various methods and instruments for determining the specific gravity of mineral substances. Commonly the sp. gr. of a mineral substance is determined in geological laboratories by Walker's steel yard balance. This is a steel yard balance working on lever principle and was invented by Walker.

Walker's steel yard balance consists of an iron stand supporting a steel yard divided into two unequal arms by the fulcrum point. The longer arm is graduated and the upper surface of the shorter arm is toothed and carries a heavy bob. The longer graduated arm moves up and down through a vertically rectangular slot fixed at the upper part of another iron stand. The slot carries a horizontal mark which marks the horizontal position of the steel yard necessary for complete equipoise.

The mineral specimen whose specific gravity is to be determined is fastened by a piece of thread and left hanging from the graduated arm and counter-balanced against the bob kept at a suitable position on the shorter arm. The reading on the graduated arm is noted. Let it be *'a'*. Then the specimen is completely immersed in water inside a beaker. Without disturbing the bob, it is again counter-balanced against the specimen immersed in water and the correspon-ding reading is taken. Let it be '*b*'.

As the instrument works on lever principle the readings, *a* and *b*, are inversely proportional to the weights of the body in air and water respectively.

As Sp. gr. $= \dfrac{W}{W-W_1}$, where W is the weight of the specimen in air and W_1 is its weight in water.

$$\text{Sp. gr.} = \frac{\frac{1}{a}}{\left(\frac{1}{a}-\frac{1}{b}\right)} = \frac{b}{b-a}$$

$= \dfrac{\text{reading when the specimen is in water}}{\text{reading when the specimen is in water—reading when the specimen is in air.}}$

The following precautions are necessary in the experiment:

(1) The bob should not be displaced for one set of readings (in air and water).

(2) The mineral specimen should be completely immersed in water and it should not touch the sides and bottom of the beaker.

(3) No air bubble should stick to the specimen. If there be any, it should be jerked off.

(4) For the second and subsequent pairs of readings water particles on the mineral specimen should be blotted off.

Crystals

Minerals sometimes form good crystals. A crystal is a regular geometric form bounded by several smooth surfaces. The regular shape is an expression of the internal atomic structure. In crystalline forms, the constituent molecules are nearly packed. There is also a definite pattern of their arrangement.

Non-crystalline forms (also called amorphous) lack in the closely packed arrangement. There is also another class which is called crypto-crystalline. In crypto-crystalline forms, the individual constituent parts have not yet attained the full crystalline state and their character is only discernible under the microscope.

Crystal Systems : Crystals are divisible into 6 divisions called systems. They are :

(1) *Isometric or Cubic System*—The crystals of this class possess three equal axes and all of them are at right angles to each other.

(2) *Tetragonal System*—The crystals of this system have three axes all at right angles to each other. Two horizontal axes are equal but the third vertical one is either shorter or longer.

(3) *Orthorhombic System*—The crystals of this system possess three axes all at right angles and all unequal.

(4) *Hexagonal System*—The crystals of this system have four axes, three equal horizontal axes cutting each other at 120^0 and the fourth vertical being unequl to the former three.

(5) *Monoclinic System*—The crystals of this system have three axes all unequal—one vertical, one horizontal and the third inclined to the vertical.

(6) *Triclinic System*—The crystals of this system prossess three unequal axes, all of which are inclined at some angles to each other.

DESCRIPTION OF MINERALS

(A) Rock-forming Group

(1) *Quartz*—Crystal system—Hexagonal. Form—Crystalline, massive, geoidal (as cavity-filling) or in grains (as in sand). Cleavage—absent. Fracture—uneven to conchoidal. Colour—generally colourless or white. Presence of impurities and inclusions impart various shades of colour, sometimes rosy (due to TiO_2), milky white, smoky (due to hydrocarbon compounds), brownish (due to iron) etc. Streak—uncoloured. Coloured varieties show paler colour in the streak. Luster—vitreous (like that of glass). Hardness—7. Sp. gr.—2·65. Crypto-crystalline forms show lower sp. gr.

(nearly 2·6). Amorphous variety shows still lower sp. gr. (nearly 2.2).

Composition—SiO_2 (Silicon Dioxide) Varieties—(a) Crystalline—Rock Crystal, Amethyst, Rosy Quartz, Smoky Quartz (Cairngorm Stone), Milky Quartz, Cat's eye, Aventurine. (b) Crypto-crystalline—Chalcedony, Agate, Carnelian, Plasma. Onyx, Flint, Hornstone, Lydian Stone, Firestone. (c) Amorphous—Opal, Hyalite.

(2) *Orthoclase*— (Potash Felspar). Crystal system—Monoclinic. Form—Commonly massive. Cleavage—perfect—two sets which are nearly at right angles. (The name has come from two Greek words—*orthos* meaning rectangular—and *clastos* meaning cleavage). Fracture—uneven. Colour—white, pink or gray. Streak—uncoloured. Lustre—vitreous Hardness—6. Sp. gr.—2·56.

Composition—K_2O, Al_2O_3 $6SiO_2$ (Potassium-Aluminium-Silicate.) Varieties—(a) Crystalline—Moonstone, Adularia, Sanidine etc.

(3) *Microcline*—Crystal system—Triclinic. Form—Commonly massive. Cleavage—perfect. Fracture—uneven. Colour—cream coloured or green. Streak—uncoloured. Lustre—vitreous. Hardness—6 (generally a bit harder than orthoclase). Sp. gr.—2·55 (generally a bit less than orthoclase).

Composition—K_2O, Al_2O_3, $6SiO_2$. (Potassium—Aluminium Silicate.)

(4) *Plagioclase*— (Soda-lime Felspars). This is another group of felspar minerals. The end members are Albite—Na_2O, Al_2O_3, $6SiO_2$ and Anorthite—CaO, Al_2O_3, $2SiO_2$. The intervening members are (after Albite) (i) Oligoclase, (ii) Andesine (iii) Labradorite and (iv) Bytownite.

The group characters are—

Crystal system—Triclinic. Form—commonly massive. Cleavage—perfect, two sets, which are nearly at right angles though not exactly. (The name has originated from two Greek words—*Plagios* meaning oblique and *Clastos* meaning cleavage). Fracture—uneven. Colour—white, gray or cream-coloured. Streak—uncoloured. Lustre—vitreous. Hardness—6—6·5 Sp. gr. – 2·6—2·76.

Composition—Silicates of Aluminium, Sodium and Calcium.

(5) *Pyroxene*—This is the name of another group of minerals like the felspars. The more important members are—(i) Enstatite (ii) Hypersthene (iii) Augite (iv) Diopside (v) Rhodonite. Crystal system—Orthorhombic (Enstatite and Hypersthene), Monoclinic (Augite, Diopside etc.) and Triclinic (Rhodonite etc.) Form—commonly massive, lamellar or granular. Cleavage—two sets, nearly at right angles. Fracture—uneven. Colour—black, dark-green or grayish. Streak—uncoloured to grayish or greenish. Lustre—vitreous. Hardness—5—6 Sp. gr.—3·2.—3·6.

Composition—Silicates of Calcium and Magnesium, sometimes also with Iron, Aluminium and Sodium.

(6) *Amphibole*—This is another group of minerals very similar to the pyroxene. In hand specimens it is very difficult to distinguish between the two groups.

The important members are—(i) Anthophyllite (ii) Tremolite (iii) Actinolite and (iv) Hornblende.

The group characters are—

Crystal system—Orthorhombic (Anthophyllite), Mono.-clinic (Tremolite, Actinolite, Hornblende etc.) and Triclinic (Aenigmatite). Form—commonly massive. Also fibrous or granular. Cleavage—perfect. Two sets inclined at angles of 124° and 56°. Fracture—uneven. Colour—black, green or grayish. Streak—uncoloured to grayish or greenish. Lustre—vitreous. Hardness—5—6. Sp. gr.—2.9—3.8.

Composition—Similar to the pyroxenes but with a little water.

(7) *Mica*—This is another group of minerals, the most important of which are muscovite, biotite and lepidolite.

(a) *Muscovite* (Potash mica)—Crystal system—Monoclinic.

Form—flaky or scaly. Cleavage—perfect, one set, basal. Fracture—not easily obtainable due to good cleavage. Colour—colourless, grayish or pinkish. Lustre—pearly. Streak—

uncoloured. Hardness—2—2.5. Sp. gr.—2.76—3. The sheets, when thin, are flexible and elastic and produce percussion figures when pressed with hard and blunt rods.

Composition—Silicate of Aluminium and Potassium with water.

(b) *Biotite*—(Iron mica)—Crystal system—Monoclinic. Form—flaky or scaly. Thin sheets are elastic and flexible and produce percussion figures. Cleavage—perfect, one set, basal. Fracture—not obtainable easily due to good cleavage. Colour—black or dark green. Streak—uncoloured, often a bit greyish or brownish due to decomposition. Lustre—pearly. H—2.5—3. Sp. gr.—2.7—3·1.

Composition—Silicate of Fe, Al, Mg and K with water.

(c) *Lepidolite*—(Lithium mica)—Crystal system – Monoclinic. Form—in scales or in grains. Cleavage—perfect, one set. Fracture—not easily obtainable. Colour—pinkish or white. Streak—uncoloured. Lustre—pearly. H—2·5—4. Sp. gr.—2.8—3.3.

Composition—Silicate of K, Li, Al with water and Fluorine.

(8) *Olivine* — Crystal system — Orthorhombic. Form—massive or granular. Cleavage—imperfect. Fracture – conchoidal. Colour—green or yellowish green. Streak—uncoloured. Lustre—vitreous. H—6.5—7. Sp. gr.—3.27—3.37.

Composition—Silicate of Mg and Fe.

(9) *Garnet*—It is also a group of minerals including the following important members—(i) Grossularite—Ca-Al garnet. (ii) Almandite—Fe-Al garnet. (iii) Spessartite—Mn-Al garnet. (iv) Pyrope—Mg-Al garnet, (v) Andradite—Ca-Fe garnet.

The group characters are—Crystal system—Isometric. Form—granular often in good dodecahedral or traphezohedral crystals. Cleavage — absent. Fracture — conchoidal. Colour—red, black or green. Streak—uncoloured. Lustre—vitreous. H—7. Sp. gr.—3·2—4.3.

Composition—$3R''O, R_2'''O_3, 3SiO_2$ where R'' stands for Ca, Mg, Fe (ous) or Mn and R''' stands for Al, Fe (ic), Cr or Ti.

As Grossularite has the composition—3CaO, Al_2O_3, $3SiO_2$.

(10) *Calcite*—Crystal system—Hexagonal. Form—crystals common. Also fibrous, granular, nodular, stalactitic and earthy. Cleavage—perfect (rhombohedral). Fracture—conchoidal but very difficult to get owing to the presence of good cleavage. Colour—commonly white or colourless. Also green, blue, red etc. Streak—white. Lustre—vitreous. H—3. Sp. gr.—2.7.

Composition—Calcium Carbonate—$CaCO_3$.

Varieties—Dog-tooth Spar, Nail-head Spar, Iceland Spar, Argentine, Stalactites, Stalagmites, Calcareous tufa, Limestone, Lithographic stone, Saccharoidal limestone, Marble, Chalk, Oolite and Pisolite.

(11) *Dolomite*—Crystal system—Hexagonal. Form—Commonly granular. Cleavage—perfect (rhombohedral). Fracture — uneven to conchoidal. Colour — commonly white, sometimes pinkish. Streak—white. Lustre—vitreous to pearly. H—3.5–4. Sp. gr.—2.8.

Composition — Calcium-Magnesium Carbonate — $CaCO_3$, $MgCO_3$.

(12) *Gypsum* — Crystal system — Monoclinic. Form—crystals often common. Also granular, fibrous or massive Cleavage;— perfect. Fracture — uneven. Colour — white, grayish white or pinkish white, Lustre—vitreous. H—2. Sp. gr.—2·3.

Composition—Hydrated Calcium Sulphate—$CaSO_4$, $2H_2O$.

Varieties—Selenite, Alabaster and Satin Spar.

(13) *Kyanite*—Crystal system—Triclinic. Form—bladed or columnar. Cleavage—perfect. Fracture—uneven. Colour —blue, bluish white, gray ·or green. Streak — colourless. Lustre—pearly. H—5—7. Sp. gr.—3.6.

Composition—Aluminium Silicate—Al_2O_3, SiO_2.

(14) *Silimanite*—Crystal system—Orthorhombic. Form —commonly in radiating needles or in fibrous aggregates. Cleavage—perfect. Fracture—uneven. Colour—grayish or brownish gray. Streak—white. Lustre—vitreous. H—6—7. Sp. gr.—3.2.

Composition—Aluminium Silicate—Al_2O_3, SiO_2.

(15) *Andalusite*—Crystal system—Orthorhombic. Form—in crystals, massive or granular. Cleavage—imperfect. Fracture—uneven. Colour—whitish, grayish or flesh red. Streak—colourless. Lustre—vitreous. H—7·5. Sp. gr.—3·1—3·2.

Composition—Aluminium Silicate—Al_2O_3, SiO_2.

(16) *Kaolin*—Crystal system — Monoclinic. Form — commonly earthy, easily falls to powder. Cleavage—perfect, basal. Fracture—uneven. Colour—white, grayish white or brownish white. Streak—white. Lustre—Commonly dull. H—2—2.5. Sp. gr.—2·6.

Composition—Hydrated Aluminium Silicate—Al_2O_3, $2SiO_2$, $2H_2O$.

(17) *Apatite*—Crystal system—Hexagonal. Form—crystals common. Sometimes granular or massive. Cleavage—indistinct. Fracture—uneven to conchoidal. Colour—generally bluish green. Streak—white. Lustre—vitreous. H—5. Sp. gr.—3.2.

Composition—Calcium Phosphate with either Calcium Chloride or Calcium Fluoride $3Ca_3(PO)_2$, $CaCl_2$ or $3Ca_3(PO_4)_2$,CaF_2.

(18) *Tourmaline* — Crystal system—Hexagonal. Form—prismatic, crystals common. Crystals sometimes slender or radiating. Also massive. Cleavage—imperfect, Fracture—uneven to somewhat conchoidal. Colour—commonly black also green, red or brown. Streak—uncoloured. Lustre—vitreous. H—7·5. Sp. gr.—3.

Composition—A complex Boro-Silicate of Aluminium with a little Magnesium, Iron and Alkali metals.

(19) *Beryl* — Crystal system — Hexagonal. Form—prismatic. Crystal—common. Also massive and granular. Cleavage—imperfect. Fracture—conchoidal. Colour—pale green, pale blue, yellowish or pinkish. Streak—white. Lustre—vitreous. H—7·5—8 Sp. gr.—2·7.

Composition—Silicate of Berylium and Aluminium, 3BeO, Al_2O_3, $6SiO_2$.

Varieties—Emerald (pale green) and Aquamarine (pale blue).

(20) *Fluorite*—(Also called *Flour Spar*). Crystal system —Isometric. Form—cubic crystals common. Also granular or massive. Cleavage—perfect. Fracture—uneven to conchoidal. Colour—white with violet tinge sometimes. Lustre—vitreous. H—4. Sp. gr.—3·2.

Composition—Calcium Fluoride—CaF_2.

(21) *Zircon*—Crystal system—Tetragonal. Form—prismatic. Crystals—common, also granular. Cleavage—imperfect. Fracture—conchoidal. Colour—colourless, grayish or brownish. Streak—uncoloured. Lustre—adamantine. H—7·5 Sp. gr.—4·7.

Composition—Silicate of Zirconium—ZrO_2, SiO_2.

(22) *Corundum*—Crystal system—Hexagonal. Form barrel-shaped crystals, often rough, also massive and granular. Cleavage—absent. Fracture—uneven. Colour—common varieties show grayish or brownish colours. Ruby is red and Sapphire is blue. Streak—uncoloured. Lustre—vitreous. H—9. Sp. gr.—4.

Composition—Aluminium Oxide—Al_2O_3.

Variety—Ruby (red), Sapphire (blue), Oriental topaz (yellow), Oriental amethyst (purple), Oriental emerald (green) Emery (grayish black).

(23) *Topaz*—Crystal system—Orthorhombic. Form—prismatic, granular. Cleavage—perfect. Fracture—uneven to subconchoidal. Colour—faint yellow, white. Streak—colourless. Lustre—vitreous. H—8. Sp. gr.—3·5.

Composition—$(AlF)_2$ SiO_4 with a little water.

(B) Ore-forming Group

Aluminium Minerals :

(1) *Bauxite*—Amorphous. Form—granular, earthy, concretionary, oolitic or pisolitic. Cleavage—absent. Fracture—sub-conchoidal. Colour—grayish white or brownish white.

Streak—grayish or brownish white. Lustre—dull, earthy. H—2. Sp. gr.—2·5.

Composition—Aluminium Hydroxide—Al_2O_3, $2H_2O$.

Antimony Minerals :

(2) *Stibnite*—Crystal system—Orthorhombic. Form sometimes in acicular crystals, commonly radiating and massive. Cleavage — perfect. Fracture — uneven. Colour — blackish gray. Lustre—metallic. H—2. Sp. gr.—6·4.

Composition—Antimony Sulphide—Sb_2S_3.

Arsenic Minerals :

(3) *Realgar*—Crystal system—Monoclinic. Form—prismatic crystals frequent, commonly granular. Cleavage—indistinct. Fracture — sub-conchoidal. Colour — orange-red. Streak—orange-red. Lustre—resinous. H—1·5—2. Sp. gr.—3·5.

Composition—Arsenic Monosulphide—AsS.

(4) *Orpiment*—Crystal system—Monoclinic. Form—generally massive or foliated. Cleavage—perfect. Fracture—sub-conchoidal. Colour — lemon-yellow. Streak — lemon-yellow Lustre—resinous to pearly. H—1·5—2. Sp. gr.—3·4.

Composition—Arsenic Trisulphide—As_2S_3.

(5) *Arsenopyrite*—(Also *Mispickel*) — Crystal system—Orthorhombic. Form — prismatic crystals frequent, also massive. Cleavage — indistinct. Fracture — uneven, brittle. Colour—tin-white to steel gray, often tarnished to copper-red on exposure. Streak—grayish black. Lustre—metallic. H—5·5 Sp. gr. 6·1.

Composition—Sulpharsenide of Iron—FeAsS.

Barium Minerals :

(6) *Witherite*—Crystal system—Orthorhombic. Form—commonly massive or columnar. Cleavage—imperfect. Fracture—uneven. Colour — white or grayish. Streak — white. Lustre—vitreous. H—3·5. Sp. gr.—4·3.

Composition—Barium Carbonate—$BaCO_3$.

(7) *Barite*— (Also *Barytes*) —Crystal system—Orthorho-

mbic. Form — sometimes in tabular crystals, also massive, granular or fibrous. Cleavage—perfect. Fracture—uneven. Colour—commonly white. Streak—white. Lusture—vitreous H—3. Sp. gr.—4·5.

Composition—Barium Sulphate—$BaSO_4$

Bismuth Minerals :

(8) *Bismuthinite*—Crystal system — Orthorhombic. Form—commonly massive, fibrous, foliaceous or in acicular crystals. Cleavage—perfect. Fracture—uneven. Brittle. Colour—grayish black or shining white. Streak—same as colour. Lustre—metallic. H—2. Sp. gr.—6·5. Easily fusible.

Composition—Bismuth Trisulphide Bi_2S_3.

Chromium Minerals :

(9) *Chromite*—Crystal system—Isometric. Form—commonly granular also massive. Cleavage—absent. Fracture—uneven. Colour—black or brownish black. Streak—brown. Lustre—Sub-metalic. H—5·5. Sp. gr.—4·6.

Composition—Oxide of Iron and Chromium—FeO, Cr_2O_3.

Cobalt Minerals :

(10) *Cobaltite*—Crystal system—Isometric. Form—in crystals, granular or massive. Cleavage—perfect. Fracture—uneven. Colour—silver-white generally. Streak—grayish black. Lustre—metallic. H—5·5. Sp. gr.—6—6·3.

Composition—Cobalt Arsenide—CoAsS or $CoAs_2$,CoS_2

Copper Minerals :

(11) *Chalcopyrite* — Crystal system — Tetragonal. Form—commonly massive. Cleavage—indistinct. Fracture—uneven. Colour—golden yellow (Hence also called fool's gold) Streak—greenish black. Lusture—metallic: H—3·5—4. Sp. gr.—4.2.

Composition—Sulphide of Copper and Iron—$CuFeS_2$.

(12) *Malachite*—Crystal system—Monoclinic. Form—crystals very rare. Commonly massive, botryoidal, fibrous or encrusting. Cleavage—indistinct. Fracture-conchoidal.

Colour—green. Streak—pale green. Lustre—often silky, otherwise dull. H—3·5—4. Sp. gr.—4.

Composition—Hydrated basic Carbonate of Copper—$CuCO_3$, $Cu(OH)_2$.

(13) *Azurite*—Crystal system—Monoclinic. Form—crystals rare. Commonly massive and earthy. Cleavage—indistinct. Fracture—conchoidal. Colour—deep sky-blue. Streak—pale blue. Lustre—vitreous to adamantine. H.—3.5—4. Sp. gr.—3·8.

Composition—Hydrated basic Carbonate of Copper—$2CuCO_3$, $Cu(OH)_2$.

Iron Minerals :

(14) *Pyrite*—(Also *Pyrites*). Crystal system—Isometric. Form—striated, cubic or pyritohedral crystals. Also massive, fibrous, reniform or granular. Cleavage—imperfect. Fracture—uneven to conchoidal. Colour—brass-yellow. Streak—greenish black. Lustre—metallic. H—6—6·5. Sp. gr.—5.

Composition—Iron Sulphide—FeS_2.

(15) *Hematite*—Crystal system—Hexagonal. Form—crystals commonly in tabular forms. Also reniform, botryoidal, scaly or foliaceous. Cleavage—indistinct. Fracture—uneven. Colour—steel-gray to brownish red. Streak—reddish brown. Lustre—metallic. H—5·5—6·5, Sp. gr.—5·2.

Composition—Iron Oxide—Fe_2O_3.

Varieties—Micaceous hematite, Specularite (scaly). Kidney ore, Martite (a pseudomorph of hematite after magnetite).

(16) *Magnetite*—Crystal system—Isometric. Form—crystals commonly octahedral. Also massive and granular. Cleavage—indistinct. Fracture—uneven. Colour—iron black. Streak—black. Lustre—metallic to dull. H—5·5.—6·5 Sp. gr.—5·1.

Composition—Iron Oxide—Fe_3O_4.

Varieties—Ordinary Magnetite and Lodestone.

(17) *Limonite*—Amorphous. Form—mammillary, botryoidal, fibrous, concretionary, earthy and massive. Colour—

brown. Streak—yellowish brown. Lustre—dull, sometimes silky. H—5·5. Sp. gr.—4.

Composition—Hydrated Iron Oxide—$2Fe_2O_3$, $3H_2O$.

(18) *Siderite*—(Also *Chalybite* or *Spathic Iron*)—Crystal system—Hexagonal. Form—crystals commonly rhombohedral. Often massive and granular. Cleavage—perfect. Fracture—uneven. Colour—ash-gray or brownish gray. Streak—white. Lustre—vitreous. H—3·5—4. Sp. gr.—3·8.

Composition—Iron Carbonate—$FeCO_3$.

Lead Minerals :

(19) *Galena*—Crystal system—Isometric. Form—cubic crystals common. Also massive and granular. Cleavage—perfect (cubic). Fracture—even to sub-conchoidal. Colour—lead-gray. Streak—lead-gray. Lustre—metallic. H—2·5. Sp. gr.—7·5.

Composition—Lead Sulphide—PbS.

(20) *Anglesite*—Crystal system—Orthorhombic. Form—in crystals, nodular or massive. Cleavage—imperfect. Fracture—conchoidal. Colour—commonly white or grayish. Streak—colourless. Lustre—commonly vitreous, sometimes adamantine. H—2·75—3. Sp. gr.—6·3.

Composition—Lead Sulphate—$PbSO_4$.

(21) *Cerussite*—Crystal system—Orthorhombic. Form—in simple twin or radiating crystals, massive or granular. Cleavage—distinct. Fracture—conchoidal. Colour—white or grayish. Streak—colourless. Lustre—commonly vitreous, sometimes resinous or even adamantine. H—3—3·5. Sp. gr.—6·4—6·6.

Magnesium Minerals :

(22) *Magnesite*—Crystal system—Hexagonal. Form—commonly massive, compact and earthy. Cleavage—perfect. Fracture—conchoidal. Colour—white, grayish white or brownish white. Streak—white. Lustre—vitreous. H—4—4·5. Sp. gr.—3.

Composition—Magnesium Carbonate—$MgCO_3$.

Manganese Minerals :

(23) *Pyrolusite*—Crystal system—Orthorhombic but usually occurs as a pseudomorph after manganite (Mn_2O_3, H_2O). Form—commonly massive, reniform or fibrous. Cleavage—absent. Fracture — uneven, brittle. Colour — iron-black. Streak—black. Lustre—metallic. H—2—2·5 Sp. gr.—4·8. It soils hand when touched.

Composition—Manganese Dioxide with a little water.

(24) *Psilomelane*—Amorphous. Colour—iron-black. Streak—brownish black. H—5—6. Sp. gr.—3·5—4·5.

Composition—Hydrated Oxide of Manganese, sometimes with a little of Barium, Sodium and Potassium Oxides.

Mercury Minerals :

(25) *Cinnabar*—Crystal system—Hexagonal. Form—commonly massive, granular or encrusting. Cleavage—perfect Fracture—uneven. Colour—reddish (intermediate between pink and scarlet). Streak—scarlet. Lustre—adamantine, dull in some cases. H—2—2·5. Sp. gr.—8.1.

Composition—Mercury Sulphide—HgS.

Molybdenum Minerals :

(26) *Molybdenite*—Crystal system—Hexagonal. Form—commonly massive, scaly, foliated or granular. Cleavage—perfect. Sectile (slices can be cut with a knife.). Colour—lead-gray. Streak—greenish lead-gray. Lustre—metallic. Feel—greasy. H—1—1·5. Sp. gr.—4·8.

Composition—Molybdenum Disulphide—MoS_2.

Nickel Minerals :

(27) *Millerite*—Crystal system—Hexagonal. Form—crystals commonly slender, usually radiating. Also in tufts like hair. Cleavage—perfect. Fracture—uneven. Colour—bronze yellow. Streak—greenish-black. Lustre—metallic. H—3—3.5. Sp. gr.—5.5.

Composition—Nickel Sulphide—NiS.

(28) *Niccolite* — Crystal system — Hexagonal. Form—

crystals rare, usually massive. Cleavage—absent. Fracture—uneven. Colour—reddish like copper. Streak — brownish black. Lustre—metallic. H—5—5·5 Sp. gr.—7·3.—7·6.

Composition—Nickel Arsenide—NiAs.

Silver Minerals :

(29) *Argentite*—Crystal system—Isometric. Form—crystals distorted, octahedral or cubic. Commonly massive or reticulated. Cleavage—indistinct. Fracture—sub-conchoidal. Colour—lead-gray (blackish). Streak—same as colour (shining). Lustre—metallic. H—2—2·5 Sp. gr.—7·3.

Composition—Silver Sulphide—Ag_2S.

Tin Minerals :

(30) *Cassiterite*—(Also *Tinstone*). Crystal system—Tetragonal. Form—crystal tetragonal. Also massive, granular and in alluvial deposits. Cleavage—indistinct. Fracture—uneven. Colour—black or brownish black. Streak—white or brownish. Lustre—adamantine. H—6—7. Sp. gr.—7.

Composition—Tin Dioxide—SnO_2.

Titanium Minerals :

(31) *Ilmenite*—Crystal system—Hexagonal. Form—tabular. Also massive, compact, granular or loose as sand. Cleavage—indistinct. Fracture—conchoidal. Colour—iron-black. Streak—black or brownish black. Lustre—sub-metallic. H—5—6 Sp. gr.—4·8.

Composition—Oxide of Iron and Titanium—FeO, TiO_2.

(32) *Rutile*—Crystal system — Tetragonal. Form — prismatic crystals, often in twins. Rarely massive and compact. Cleavage — indistinct. Fracture — uneven. Brittle. Colour — reddish brown or black. Streak — pale brown. Lustre—metallic. H—6—6·5. Sp. gr.—4·2.

Composition—Titanium Dioxide—TiO_2.

Tungsten Minerals :

(33) *Wolfram*—Crystal system—Monoclinic. Form—tabu-

lar, also massive and bladed. Cleavage—perfect. Fracture—uneven. Colour—reddish brown or brownish black. Streak—chocolate brown. Lustre—sub-metallic. H.—5—5·5 Sp.gr.—7·5.

Composition—Tungstate of Iron and Manganese—(Fe, Mn) WO_4.

Zinc Minerals :

(34) *Sphalerite*—(Also *Zinc Blende*). Crystal system—Isometric. Form—crystals commonly tetrahedral. Also massive, compact and rarely botryoidal or fibrous. Cleavage—perfect. Fracture—conchoidal. Colour—black, brown, rarely yellow. Streak—brownish or white. Lustre—resinous. H—3·5—4. Sp. gr.—4·1.

Composition—Zinc Sulphide—ZnS.

Native Elements :

(35) *Sulphur*—Crystal system—Orthorhombic. Form—crystals pyramidal. Also massive, encrusting and in powder. Cleavage—indistinct. Fracture—uneven. Colour—straw-yellow (lemon like). Streak—white. Lustre—resinous. H—1·5—2·5. Sp. gr.—2.

Composition—Sulphur—S.

(36) *Graphite*—(Also *Plumbago*). Crystal system—Hexagonal. Form—commonly foliated, scaly, granular or earthy. Cleavage—perfect (basal). Sectile. Colour—grayish black. Streak—same as colour. Lustre—metallic. H—1—2. Sp. gr. 2·1. Feel—greasy.

Composition—Carbon—C, but contains some impurities like Ferric Oxide and clayey material.

(37) *Diamond*—Crystal system—Isometric. Form—commonly in octahedrons, also in twins. Cleavage—perfect. Fracture—conchoidal. Colour–colourless, yellowish, bluish, grayish or black. Streak—none. Lustre—adamantine when cut, often greasy when fresh and uncut. H—10. Sp. gr.—3·52. Feel—greasy.

Composition—Carbon—C.

Varieties—Bort (gray diamond), Carbonado (black diamond), Ballas (diamond grains forming a round mass).

CHAPTER IV

COMMON ROCKS

Rocks are aggregate of minerals and are units of which the earth's crust is composed. They are pages upon which the earth's history is written and a study of them is essential for the proper understanding of the science of the earth. Rocks can be broadly divided into three main classes—(i) *Igneous*, (ii) *Sedimentary* and (iii) *Metamorphic*.

As already pointed out, the earth started its career in a state of burning gases. In its revolution through space it began to radiate heat and consequently began to cool. From the gaseous state the earth first passed into the liquid state and then into the solid state (at least on the upper surface). This solidified rock type is the *igneous* variety. The word *igneous* is derived from the Latin word *Ignes* meaning fire. This is because of the fact that such rocks are formed from the molten and heated liquid material. The molten rock material, together with the gas content, is called the *magma*. Igneous rocks are formed from the solidification of magmas.

When the surface of the earth sufficiently cooled to hold water, oceans and other areas full of water came into existence. From that time began the destruction of the upstanding masses by the different agencies of erosion. The products of erosion of all the denuding agents were brought to lakes, seas or oceans and by the consolidation of such sediments, *sedimentary* rocks were formed. This is about the first-formed sedimentary rocks. Later sedimentary rocks have been formed from sediments derived from other igneous, sedimentary or metamorphic rocks.

The igneous and sedimentary rocks later are subjected to heat and pressure accompanying crustal movements. The effect of these is to change the characters of the pre-existing rocks and in this way the *metamorphic* rocks result.

Detailed discussion of these rocks is given below.

Characters of the Igneous rocks :

These rocks have been formed by the solidification of very hot molten rock material called magma. Such rocks originate generally at depth but sometimes are formed upon the surface of the earth. Others are formed when their magmas are arrested in their upward ascent somewhere below the crust and solidify there. Upon this there have been recognised two distinct classes of igneous rocks—one *plutonic* or *abyssal* (*intrusive*) and the other *volcanic* (*extrusive*)

The plutonic rocks are those which have solidified at some depth below the surface of the earth. They are seen only after long-continued deep erosion. The environment and condition under which plutonic rocks solidify are quite different from those under which volcanic rocks solidify. Upon the crystallisation of plutonic rocks pressure acts and therefore the rate of cooling is slow and dissolved gases can not escape. This produces a coarse-grained or phaneritic texture. In the case of the volcanic rocks there is no effect of pressure and the gases also escape easily. This produces a high rate of crystallisation and a consequent fine-grained or aphanitic texture.

The demarcation line between these two groups is not always clear and commonly a third middle group is recognised. These are the *hypabyssal* rocks. As it is intermediate in its mode of origin between a plutonic and a volcanic rock, its character is also intermediate between the two groups. This type commonly shows a medium-grained texture.

Igneous rocks show a definite order of crystallisation. They commonly present an interlocking texture and a massive and hard appearance. They do not contain any fossil as the sedimentary rocks nor do they show any clear stratification like them, though at times the piling of lava flows, one after another, may produce a deceptive stratified aspect. The parallel arrangement of minerals peculiar to metamorphic rocks is also absent in the igneous rocks.

More Common Igneous Rocks :

Acidic. (1) *Granite*—The name is bacause of the well developed grains. It is the most common variety of igneous rocks in the continental sector. It is medium to coarse-grained and is generally light coloured. In composition the silica percentage is quite high (65—80 p.c.) and this puts the rock into the acidic group. Mineralogically granite consists essentially of quartz and felspar. Generally orthoclase is the variety of felspar present, though at times plagioclase may also be present. Micas, both muscovite and biotite, are frequent. Sometimes hornblende is also seen. Accessory minerals include magnetite, apatite etc.

Rhyolite is the volcanic equivalent of granite.

(2) *Pegmatite*—This type of rocks occurs as dikes and veins cutting across the country rocks. They are frequent in ancient rocks. Pegmatites are generally of granitic composition. During the late stage of crystallisation of a magma, the residual part becomes generally very rich in volatile matter, alkali and silica. The presence of volatiles and relative freeness from interference from too many minerals produce very big crystals. Commonly quartz, orthoclase and mica (both muscovite and biotite) are present and with them there is sometimes a host of accessory minerals, sometimes of great economic importance, like apatite, tourmaline, topaz, lepidolite, beryl, cassiterite etc.

Intermediate. (3) *Syenite*—The name has been derived from Syene in Egypt. It is also a medium to coarse-grained rock, very similar to granite at the first sight. The distinction between granite and syenite lies in their mineralogical and chemical composition. Mineralogically syenites generally do not contain quartz or very little of it. Chemically the silica percentage is lower (50—65%). Orthoclase is adundant. Plagioclase is frequent. So also hornblende. Pyroxenes are rare. Accessory minerals include elaeolite, nepheline, leucite, apatite, magnetite, mica etc.

Trachyte is the volcanic equivalent of syenite.

(4) *Diorite*—It is a medium to coarse-grained rock generally darker in colour than the preceding ones. It has a silica percentage of 50—65 (same as syenite). The distinction between syenite and diorite lies in the fact that the alkali percentage is lower in diorite whereas the calcium and ferro-magnesian minerals have greater percentage. Orthoclase is commonly absent while plagioclase is always present. Biotite, hornblende and pyroxene are also present to a more or less extent. Quartz is sometimes present as an accessory mineral.

Dacite and *Andesite* are the volcanic equivalents.

Basic. (5) *Gabbro*—It is a medium to coarse-grained plutonic rock of dark colour and low silica percentage (40—50%)- Plagioclases and pyroxenes are the important minerals in gabbro. Olivine is a common accessory mineral.

(6) *Dolerite*—It is the hypabyssal equivalent of the gabbro type of rocks. It is medium to fine-grained. Chemically they present the same composition as gabbro.

(7) *Basalt*—It is the volcanic equivalent of the gabbro type. It is the most common volcanic rock. Basalt is fine-grained in texture and dark in colour. Chemically it contains lime-rich plagioclases and pyroxenes as the primary minerals. Accessory minerals include olivine, iron ores, sphene, ilmenite, leucite, nepheline etc. Trap (derived from the Swedish word *trapf* meaning stair) is a general term applied to basalt because they often present a stair-like aspect on weathering (C.f. The Deccan Trap).

Ultra-basic. (8) *Peridotite*—It is a coarse-grained rock of dark colour. It is a very basic type of rock consisting mostly of ferro-magnesian minerals. Constituent minerals are generally pyroxenes, olivine and hornblende. Accessory minerals include ilmenite, garnet, chromite, sphene etc.

Structures Associated with Igneous Rocks :

(1) *Dike* or *Dyke*—The word dike is of Scotch origin meaning a wall of stone. These are wall-like masses of igneous rocks cutting across a country rock which may be either

igneous, sedimentary or metamorphic. They are formed by the consolidation of magmatic material which has penetrated through fissures in the rocks. Their structure is clearly seen when they occur in sedimentary rocks because in that case they are seen to cut across the bedding planes of the sedimentary rock. Sometimes dikes are vertical. Generally they are less than 10 ft. thick. Their breadth is moderate whereas their length is great, sometimes extending over 100 miles. They are generally of hard material and erosion often removes surrounding parts of the country rocks leaving them in upstanding wall-like positions. Sometimes (but rarely) they are also eroded at a faster rate and form ditches. Commonly they produce baking effect on the two sides in the country rock and together with the indurated sides they form wall-like barriers. Dikes are abundant in regions of tension. Sometimes dikes develop perpendicular cracks and joints due to contraction following cooling. Dikes sometimes occur in swarms of parallel disposition, sometimes radially, in ring-like forms and sometimes in inclined forms enclosing cone-like masses (PL—1).

(2) *Veins*—These are more or less irregular and branching masses of igneous material cutting across the country rock of igneous, sedimentary or metamorphic rocks. Veins are often metalliferous and of great economic value. They are generally off-shoots from bigger igneous masses.

(3) *Stringers*—They are smaller and finer veins.

(4) *Apophyses*—They are tongue-like masses given out by greater igneous masses.

(5) *Sills*—These are sheet-like masses of igneous material which have penetrated into the country rock, and have spread parallel to the bedding planes as if forming additional layers in the invaded rock body. These sills are therefore clearly seen in sedimentary rocks. They may be horizontal or inclined. Sills vary in thickness from a few inches to tens of feet. Their length and breadth depend upon their spreading capacity which is again dependent on the fluidity of their material, its temperature and the weight of the overlying rocks

to be lifted. Commonly sills present a lenticular form when traced to great distances. Sills are sometimes multiple in form, occuring one after another. Sills and dikes are inter-related bodies. Often a dike gives off a sill-like mass and a sill passes into a dike-like mass as shown in the figure.

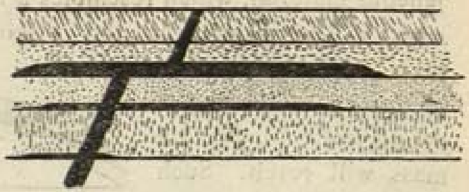


Fig.—2
Dike and Sill

Distinction between a sill and a contemporaneous lava flow

(a) Sills produce baking effects on rocks on both sides of them whereas in the case of lava flows, the baking effect is to be seen only on the lower side.

(b) Lava flows show irregular upper surfaces whereas sills have two more or less flat and parallel sides.

(c) Lava flows present spongy and scoriaceous upper sides whereas sills present hard and more or less plane upper surfaces.

(d) Lava flows often show glassy or very fine-grained rocks, whereas sills show medium-grained and often porphyritic textures.

(e) Sills often give out tongues in the overlying rock mass whereas lava flows do not.

(6) *Laccoliths* (or *Laccolites*)—These are lens-shaped structures formed by igneous rocks pushing up the overlying rocks. Laccoliths are formed by highly viscous materials which can not spread to great distances. Consequently they make their room by uplifting the overlying rocks and dome-shaped forms result in this way which are called laccoliths. Laccoliths are fed by slender necks and they have a circular flat bottom. Laccoliths are formed under-ground and come to sight only after long-continued erosion.

Fig.—3
Laccolith

(7) *Bysmaliths*—This is a type of structure made by igneous material, which resembles a laccolith. In the extreme case, if the magma be too viscous, then the overlying mass will be uplifted producing faults and a cylindrical p l u g-l i k e mass will result. Such forms are called bysmaliths.

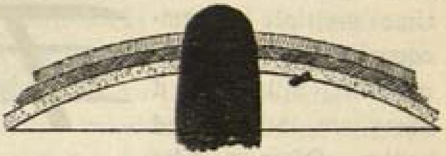


Fig.—4
Bysmalith

(8) *Lopoliths*—The word lopolith has been derived from a Greek word *lopas* meaning a basin. Such forms are exactly like teaspoons. They have more or less flat tops and sunken bases in the form of basins.

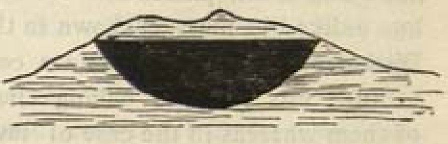


Fig.—5
Lopolith

(9) *Phacoliths*—These ar elens-shaped bodies of igneous rocks which occur in folded strata. During folding the anticlinal parts become very weak and in these regions igneous materials cellect to foım lens-shaped bodies which are called phacoliths.

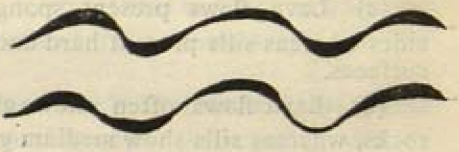


Fig.—6
Phacolith

(10) *Batholiths*—(or *Bathyliths*)—These are huge masses

Fig.—7
Batholith

of igneous rocks formed at some depth below the earth's surface and they come to sight only after the removal of the over lying masses. They are without visible floors and have steep-sided walls. They are generally found in mountain areas as cores. The formation of a batholith is closely related to mountain-building. Batholiths make their way upwards by melting the overlying rocks or by breaking and mixing (stoping). Mountain building. processes produce some regions of weakness, if not actual empty spaces, at the core and these are later filled up by batholithic masses.

(11) *Stocks*—These are smaller masses very similar to batholiths in form.

(12) *Bosses*—These are also stock-like masses but have circular outcrops.

(13) *Chonoliths*—Other forms which do not come under the preceding regular forms are grouped under the term chonolith. They are irregular masses occuring in dislocated rocks.

So far about the plutonic and hypabyssal structures. The volcanic structures have been dealt in the chapter on volcanoes and volcanism. (Chapter—XIV).

SEDIMENTARY ROCKS

Characters of Sedimentary Rocks :

Sedimentary rocks, as the name implies, are those rocks which have been derived from the consolidation of sediments. These sediments are the products of erosion, both mechanical and chemical, from some pre-existing rock masses. The sediments are carried both in suspension as well as in solution and are deposited in basins like lakes and more commonly in seas and oceans. In case of marine deposits, remains of marine animals and plants also contribute to the accumulating mass. The consolidation of these products by pressure or by cementing materials like silica, calcium carbonate and iron oxide, produces a more or less hard rock mass. Such masses are called *sedimentary rocks.* One of the characteristics of the sedimentary rock is the conspicuous layering seen in such rock masses. Commonly this layering or stratification, as it is called, is horizontal, although it may be inclined as well. Sedimentary rocks contain fossils which are the remains of ancient animals and plants. The interlocking character of minerals, which is seen in igneous rocks, is absent here. The characteristic parallel arrangement of minerals seen in metamorphic rocks is also absent here.

The *layering* in sedimentary rocks is due to sedimentation with cessations due to a change of the velocity of the transporting agent or any change in the supply. It may also be due to the sedimentation of materials of different composition, texture and colour. Distinct layers are thereby produced. The separating plane between two layers is called a *bedding plane* and each individual layer is a *stratum*.

More Common Sedimentary Rocks :

Sandstone—This is the rock formed by the cementation of sand grains into hard mass. Silica generally constitutes the main mass. Depending upon the cementing material, the colour of sandstones at times becomes red and brown (ferruginous sandstone with iron oxide as the binding material) and white (sandstone when calcium carbonate, kaolin or silica is the binding material). When there is a considerable amount of mica in the sandstone it is called micaceous sandstone. Similarly when there is a considerable amount of felspar it is called felspathic sandstone. The individual grains of sand in sandstones are nearly round specially in the case of water and wind-borne sediments. These sand grains vary in size and several types have been recognised as—

(1) Boulder—with a size bigger than that with a diameter of 256 m.m.

(2) Cobble—with a size having a diameter between 256—64 m.m.

(3) Pebble—with a size having a diameter between 64—2 m.m.

(4) Gravel—with a size having a diameter of 2 m.m. nearly.

(5) Sand—with a size having a diameter between 2—0·02 m.m.

(6) Silt—with a size having a diameter between 0·02—0·002 m.m.

(7) Clay—with a size having a diameter less than 0·002 m.m.

The sixth and the seventh varieties will form *siltstone* and *shale* and not sandstone. In the fifth variety there are coarse, medium and fine-grained sands.

Upon the size of the constituent grains, there are several types of sandstones like fine-grained sandstone (as Raniganj sandstone), medium-grained sandstone and coarse-grained sandstone (as Barakar sandstone). The fine-grained variety points to comparatively deep water deposition than the coarse-grained variety. Very coarse-grained sandstones formed by water-worn gravels and pebbles cemented in a matrix, which may be siliceous, calcareous, clayey or ferruginous, are called *conglomerates* (PL—2). They are also called *puddingstones* because of their resemblance to pudding. There are two types of conglomerates such as—(1) Intra-formational conglomerates and (2) Autoclastic conglomerates.

(1) *Intra-formational Conglomerates*—These are formed at the time of deposition of the strata containing them. This is possible when parts of the strata are broken by earth movements or otherwise rounded by rolling and then cemented.

(2) *Autoclastic Conglomerates*—They are formed by breaking and rolling up of quartz veins or similar rocks by earth movements. The Dharwar conglomerates were thought by some to be of autoclastic origin. The distinction between intraformational and autoclastic conglomerates is that the former was formed at the time of deposition of the rocks containing them while the latter was formed later than the strata containing them.

Conglomerates serve a very important purpose in stratigraphy. Unconformities are sometimes marked by them and hence their presence indicates break in sedimentation and so they are used in marking the beginning and end of rock formations.

(a) *Arkose* is a variety of sandstone in which there is a considerable percentage of felspars, more or less resembling a granite in appearance. They weather very easily.

(b) *Grit*—It is a variety of hard sandstone in which the grains are coarse and angular.

(c) *Graywacke*—This German term denotes a variety of sandstone, usually gray in colour, which has been derived from some basic igneous rocks or argillaceous rocks. In addition to quartz grains, they contain some ferro-magnesian minerals.

(d) *Flagstone*—It is a variety of sandstone which breaks very easily into thin slabs and is used as paving and roofing material. The good cleavage is due to the presence of micaceous and argillaceous mat erial.

(2) *Limestone*—This is a sedimentary deposit of calcium carbonate. The deposition of calcium carbonate, mostly calcite, either from solutions or from the remains of the dead bodies of marine animals, makes the formation of limestone rocks. Formation of calcareous deposits from solutions has been discussed in the chapter on underground water (Chapter-VIII). Sea animals also contribute to a large extent in the formation of limestone rocks. These animals take up calcium carbonate from sea water and build up their shells in which they live. After the death of these animals the shells sink to the sea bottom and their gradual accumulation forms limestone rocks. Sea animals like foraminifers, corals, crinoids etc. have great reputation as rock-builders. This has been discussed in the chapter on oceans (Chapter—VII). There are many varieties of limestones such as :—

(a) *Marl*—It is an impure variety of limestone containing, besides calcium carbonate, a considerable amount of clayey material. Marls of suitable composition are sometimes used as cementing materials.

(b) *Dolomite*—This is a variety which contains a good amount of magnesium carbonate. Limestones often change to dolomites. The original calcium carbonate changes to carbonates of calcium and magnesium by the percolation of magnesium salt solutions. The composition of dolomite is $CaCo_3$, $MgCO_3$.

Dolomitisation of limestone is often an important change in calcareous deposits. When the percentage of magnesium is low, the limestone is called magnesian limestone and when the percentage of magnesium is quite appreciable, the limestone is called dolomite.

(c) *Chalk*—It is a soft, loose variety of limestone in which of foraminiferal shells are abundant sometimes.

(d) *Coquina*—It is a variety of shelly limestone.

(e) *Oolite* (or *Oolitic Limestone*) — It is a variety of limestone in which the constituent parts are like small globules, just like fish roe.

(f) *Pisolite (*or *Pisolitic Limestone)*—It is a variety of limestone in which the constituent parts are bigger globular masses than those of oolite. They are like peas in pisolile.

(3) *Shale*—It is a variety of sedimentary rock which is formed by the consolidation of clay and mud. Clay is hydrated aluminium silicate in chemical composition and is formed as an alteration product of felspars in humid temperate climate. Such clays with very fine particles of mica and sand consolidate to form rock masses which are called shales and mudsstones. Shales are distinguished from mudstones by the presence of good divisional planes in them (shales) along which they break easily. When these planes are absent or inconspicuous, shales pass on to the mudstone variety.

(a) *Argillite*—This is a variety of clayey rock which is harder than mudstone and the shaly fracture is more or less absent.

(b) *Fireclay*—It is a variety of clayey rock which is commonly found in coal fields underlying the coal seams. It is so termed because it can withstand high temperature without melting. This is because, these clays, unlike ordinary clays, lack in alkali and iron materials. These materials were extracted from the soil upon which the trees, later to form coal seams, flourished in bygone days. These are used as refractory substances.

(c) *Siltstone*—It is a variety of sedimentary rocks which is formed by the consolidation of silt materials. The constituting materials have bigger grain size than those of shale and mudstone which consist of materials in the microscopic state of sub-division.

Structures Associated with Sedimentary Rocks :

(1) *Stratification*, lamination or layering which has been already referred to (PL—3).

(2) *Ripple marks*—These are wave-like surfaces produced on the sediments by the action of currents in shallow water. They may also be found on wind formed deposits. Individual wave or ripple may show a symmetrical pattern (PL—4).

(3) When soft alluvium is left exposed to air and the sun's rays for a considerable time, it dries up and shrinks. During shrinking polygonal cracks develop. They are called *mud cracks or sun cracks* (PL—5). They are most frequent where there are chances for alluvium to spread in thin layers over great areas and to get dried. Flood plains are therefore the ideal areas where mud cracks are frequently seen. Mud cracks are often preserved by being quite hardened and then quickly burried under sediments. Likewise *rain drops* and *foot prints of animals* are found preserved in ancient sedimentary rocks.

(4) *Graded bedding*—When sediments settle in suspension, the larger and heavier particles reach the bottom first and the lighter and the finer ones later. This produces an assortment of the sediments and the bedding thus produced shows larger and heavier pieces in the bottom layers and gradually finer ones in the overlying layers. Such a type of bedding is called graded bedding.

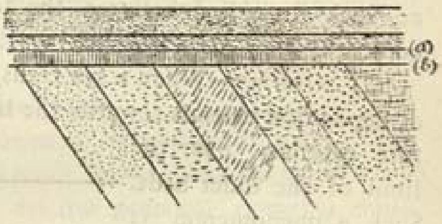
(5) *Cross-bedding* or *Current bedding* or *False-bedding*–This is another characteristic structure met in shallow water and wind formed deposits in which the layers of sediments are inclined to one another instead of following a general parallel

stratification which is so characteristic of sedimentary rocks. There is no common bedding plane and no bedding plane extends over a great length (PL—6).

(6) *Unconformity*—When groups of strata have parallel bedding planes they are called *conformable* strata and they are said to possess *conformity*. Sometimes however this parallelism is lost and one set of beds may have the bedding planes inclined to those of another set. They then lack in conformity and are said to possess *unconformity* which indicates some dissimilarity between the two sets of beds (PL—7).

There are two types of unconformity—(i) *Non-conformity* and (ii) *Disconformity*.

(i) *Non-conformity* means angular unconformity between two sets of beds. When two sets of beds are inclined to each other at an angle, they are said to possess non-conformity.

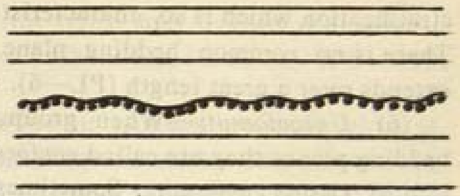


Fig—8
Non conformity

In the figure the set of beds marked (a), has a different inclination from that of the other set marked (b). These two sets are therefore said to possess non-conformity.

(ii) *Disconformity*—Suppose a set of beds, which was first deposited, has been uplifted to form land at a later period. When the beds have formed land, there will be no deposition. Suppose at a still later period the area has been depressed and gone under the sea again. Deposition will again begin and a new younger set of beds will be formed. These two sets of beds have been formed at different periods and possibly under different conditions. There exists a discordant relationship between the two sets of beds which is generally marked by an irregular surface and a bed of conglomerates at the base of the new set of beds. Such a discordant relationship between the two sets of beds is called disconformity. Disconformity is generally marked by a conglomerate bed.

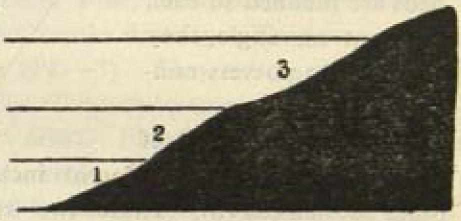
Unconformities serve important functions in stratigraphy. In grouping of strata and in the establishment of relation between rocks of different areas, the presence of unconformities is very useful.



Fig—9
Disconformity

Unconformities denote two different conditions of rock formations and altogether different geological conditions. They also denote some crustal disturbances and a period of no rock formation between the formation of unconformable beds.

(7) *Overlap*—When a sea transgresses upon land, the area of deposition extends towards the land. Each new bed, therefore extends over the limit of the older beds. Such a phenomenon is called overlap. Overlap denotes transgression by seas which may be due to either the rise of the sea level or the sinking of the land area.



Fig—10
Overlap

(8) *Offlap*—The reverse phenomenon in which the younger beds are shorter than the older beds and lag behind them is called offlap. Offlap denotes regression of seas either as a result of the lowering of sea level or sinking of sea floor or rising of the land areas.

Metamorphic Rocks

The word metamorphic or metamorphosed means changed. Metamorphic rocks generally result from the changes brought about by heat, pressure and chemical agencies, upon pre-exsisting igneous and sedimentary rocks. Those derived from igneous rocks are called *orthometamorphic* rocks and those derived from sedimentary rocks are called *parametamorphic* rocks. The work of heat, pressure and chemical solution is to produce some well defined characters upon metamorphic rocks. Metamorphic rocks are generally coarsely crystalline which distinguishes them from the sedimentary rocks. There is some parallel arrangement of minerals (foliation) which distinguishes them from the igneous rocks. They have peculiar texture. There are some minerals which are only to be seen in metamorphic rocks. The minerals are—kyanite, andalusite, sillimanite, zoisite, wollastonite, staurolite etc. There are different kinds of metamorphism produced by different agencies and there are correspondingly different products. Metamorphic rocks present some banded appearance and sometimes well developed cleavages.

More Important Metamorphic Rocks

(1) *Gneiss*—This is a common metamorphic rock. Gneiss is coarse-grained and generally shows a banded appearance. Quartz, felspars and mica are the generally occuring minerals. Accessory minerals include hornblende, augite, biotite etc. by which they are named (such as hornblende-gneiss, augite-gneiss etc.) Gneisses are sometimes produced by the metamorphism of granite type of rocks. They may also be derived from some sedimentary rocks. Gneisses are the most commonly occuring type in ancient rock masses (PL—8).

(2) *Marble*—It is the metamorphosed variety of limestone. The change produced is the appearance of a granular and crystalline character. Marble may be of many colours—white, gray, yellow, black etc. Generally it is white or light coloured. Sometimes marbles are dolomitic in composition. Marbles can be easily worked because of their softness and hence form very good ornamental building stones.

(3) *Quartzite*—This is the metamorphosed equivalent of sandstone and consists mostly of quartz. Quartzites are very hard. They often occur as veins cutting across other metamorphic rocks.

(4) *Slate, Phyllite and Schist—Metamorphism of Clayey Rocks*—

Gradual compaction produced by gradual increase in pressure produces considerable changes upon clayey deposits. The first effect is to produce shale or mudstone from clay which are sedimentary rocks. More pressure produces successively slate, phyllite and finally schist. In *slates* the minerals are very fine grained. Most notable is the presence of a well developed cleavage which is called the slaty cleavage. The easy plane of fissility renders it very suitable for being used as roofing material in thin slabs.

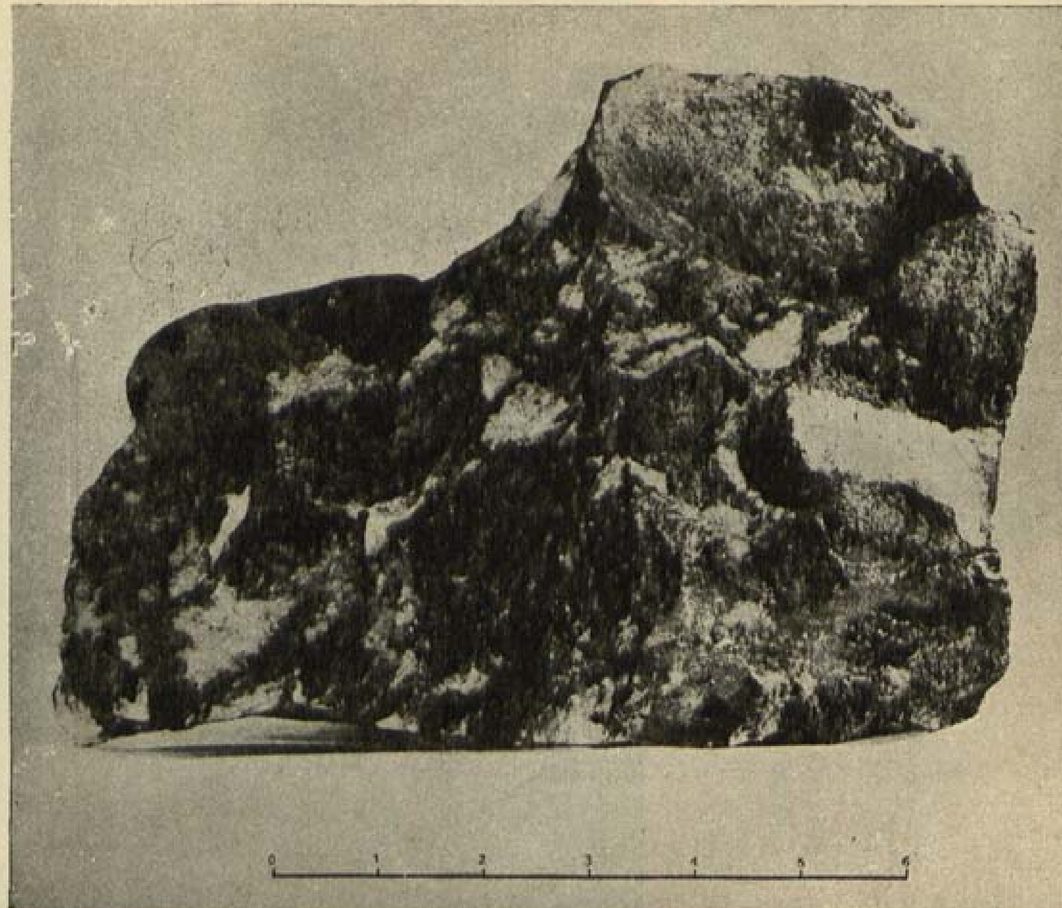
(5) *Phyllite*—These are produced with more pressure. They are more or less slate-like in appearance. The only difference is that phyllites have a glossy and shining appearance which is due to the formation of incipient mica flakes.

(6) *Schists*—Further metamorphism produces schists although they may also be derived from some basic igneous rocks. Schists possess well defined foliated or leaf-like appearance which is so characteristic that it is also called schistose structure. Micas, quartz, chlorite, kyanite, graphite, hornblende etc. are their constituent minerals. In schists also there are some minerals which mark gradual increase in the grade of metamorphism. They are (in order of increasing grade)—chlorite, biotite, garnet, staurolite, kyanite and sillimanite.

Two more rock types which are products of alteration of pre-existing rocks may be considered here. They are—

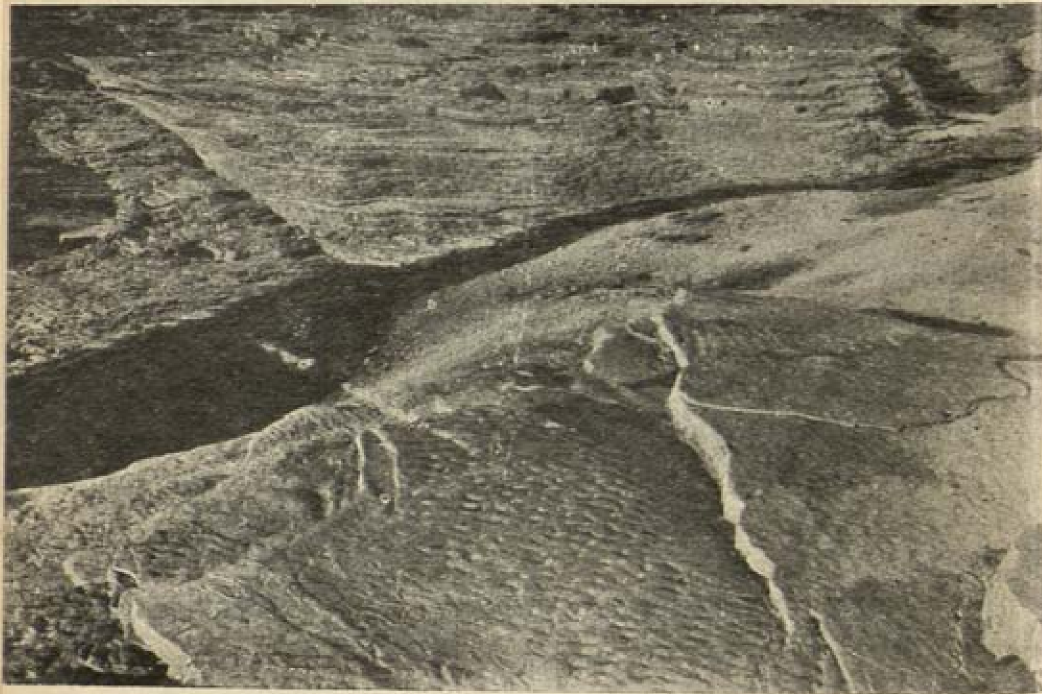
(a) *Laterite*—The word has come from the Latin word Later meaning brick because in India laterite slabs are used as building material. When freshly cut laterites are rather soft and can be cut into brick like slabs but on exposure to the atmosphere they harden. This is brownish in colour and is composed mainly of the hydroxides of iron and aluminium, and sub-ordinately of the hydrated oxide of manganese. At places the percentage of titanium oxide becomes considerable. There is very little silica, magensium, calcium and alkali materials which have been leached out from the parent rock material. There is very little of humus also. Basalts generally

Pl.—1
Ramifying dolerite dikes in
Erinpura Granite
(By courtesy, Director, G.S.I.)



Pl.—2 Conglomerate with large rounded pebbles, Durgahati Piparia, Jabalpur
(By courtesy, Director, G.S.I.)

Pl.—3
Stratification in Vindhyan Lime:tone and Shale



Pl.—4 Ripple marks on Glauconite beds of the Semri series (Lower Vindhyan)
(By courtesy, Director, G.S.I.)

Pl.—5
Mudcracks

but granites and gneisses also give rise to laterite under peculiar tropical monsoonic climate with seasonal rainfall and alternating drought. There are two types of it—(i) *high level laterite* and (ii) *low level laterite*. The former type is formed at an altitude greater than 2000 ft. and is found in Bihar, Orissa, M. P. and Assam. The later type is formed at lower altitudes, even in some coastal areas, and is found in West Bengal and Madras.

(b) *Regur or Black Cotton Soil*—This has resulted from the decomposition of the Deccan basalts and occurs widely in Bombay. It contains a high percentage of the oxides of calcium, magnesium, iron and alkalies and is very fertile. It becomes very hard after it is moistened with water and then develops cracks on drying. It is extensively cultivated for cotton growing.

CHAPTER V

WEATHERING OF ROCKS

Ever since the consolidation of the earth's crust and the formation of water upon the earth, after it has sufficiently cooled, the rocks have been subjected to the wearing effects of geological agents like the running water, wind, sea waves, glaciers etc. The rocks have been attacked and bit by bit they have been made smaller and smaller. The worn down particles are then taken away from the place of their formation to be deposited elsewhere and their gradual consolidation makes the sedimentary rocks. Quite distinct sets of processes operate in the wearing of the rocks which will be discussed in this chapter.

Weathering involves the process of breaking of rocks to smaller particles and decomposition of the rocks. When the products of weathering are removed from the place of formation, the process is called *erosion.* The distinction between weathering and erosion lies in the fact that in erosion there is the transport of the products to other distant places whereas in weathering there is practically no such transport excepting for short distances by gravity. According to the transporting agent, erosion may be *fluvial erosion* (by river water), *glacial erosion* (by glaciers), *wind erosion* (by wind) and *marine erosion* (by sea water).

Weathering involves two distinct processes—one mechanical breaking or *disintegration* and the other chemical *decomposition.*

Factors influencing Weathering :

(a) Physical Factors—

(1) *Frost-action* or *frost-wedging*—This depends upon the well known property of water at its freezing point. When water freezes it expands by nearly one-tenth of its volume. Therefore when water, which has percolated into the cracks of rocks, freezes with the fall of temperature, the increase in volume

will exert tremendous pressure upon the walls of the rocks. The ultimate result will be that the rocks will be broken to pieces. This sort of disintegrating action is called frost-action. Frost-action is very conspicuous in regions of high altitudes and high latitudes. At day time water will percolate down the cracks of the rocks and at night when the temperature will fall, frost-action will take place. The presence of joints and cracks in the rocks helps the frost action to a considerable exent by allowing water to penetrate inside the rocks.

Frost-heaving is another similar effect which is caused by the expansion of water when it freezes. In inclined surfaces rock particles will be upheaved by the expansion of water below by freezing. The upheaved particles will then be acted upon by gravity and will be displaced.

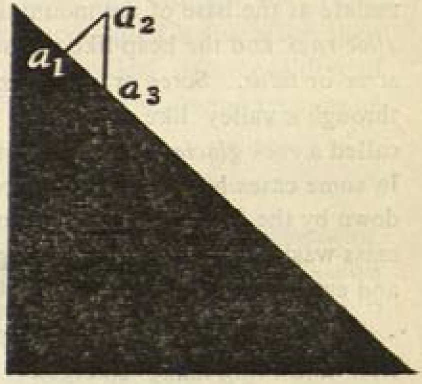


Fig.—11
Frost-heaving

(2) *Temperature changes*—With one or two exceptions like ice and some alloys, heat expands every solid. In desert regions rocks are highly heated by the scorching rays of the sun. The outer layer therefore expands considerably and gets detached from the main mass. Then again all the minerals do not expand to the same extent by heating. This differential expansion of minerals also produces distintegration of rocks.

Exfoliation is a process in which thin shells of rocks are detached from the main mass layer by layer and this produces a more or less round mass. Such a sort of weathering is called *spheroidal weathering* and the main rounded mass thus produced is called a *residual boulder*. Granites and basalts are specially susceptible to this sort of spheroidal weathering (PL—10). The attack at first starts from the corners and gradually they are worn down and this produces a round mass after which thin concentric layers are weathered off. Apart from temperature changes, chemical changes specially hydration of minerals also help in exfoliation.

(3) *Action of gravity*—This helps in weathering by exposing fresh surfaces of rocks by the removal of the weathered upper surfaces by slow downward movements of the loosened particles. In steep mountainous regions loosened weathered particles will fall down by the attraction of gravity and accumulate at the base of the mountain. The fragments are called *slide rock* and the heap-like masses formed by them are called *scree* or *talus.* Scree or talus may at favourable places flow through a valley like a stream. Such a moving rock mass is called a *rock glacier* because of its resemblance to a glacier. In some cases huge quantity of rock material sometimes slides down by the forces of gravity and other causes, and cause mass-wasting. Such sliding of huge quantity of rock fragments and earthy material is called *rock slide* or *land slide* (PL—11).

Land slides often come suddenly and cause wide destruction and bring many changes. Rivers are often blocked to form lakes. Gohana lake in Garhwal was formed in this way when nearly 5000 million tons of crushed pyrite-bearing shale and dolomitic limestone having an inclination of 45° slipped through a distance of 3000 ft. after a heavy shower of rain filling the valley of the Birahi Ganga, 2 miles wide and 850 ft. deep. Land sildes are occasional, but loosened masses of rocks in mountain masses generally have a tendency to move slowly downward. Such a slow movement is called *creep.* Creep is greatly facilitated by the lubricating action of water. *Solifluction* is a special kind of creep in which a rock mass which has been moistened by water to a considerable depth slides downward.

(4) *Water*—Weathering action of running water is of great magnitude. Water causes weathering chemically by solution and mechnically by breaking the rock mass by its dashing action.

Wind—It has been separately treated in the chapter on wind action (Chapter—IX)

(b) Biological Factors—

(6) *Animals and Plants*—Animals often produce heaps of earth which are easily removed away. Trees and plants by striking roots into the ground loosen the particles and widen the cracks. Subsequently rain-fall and wind easily remove them away. Moreover both animals and plants produce some toxic products which help in chemical solution of rocks. Plants produce an organic product called *humus* after their decay which is very helpful in chemical decomposition of rocks. Becteria is of great importance in the decomposition of rocks.

(c) Chemical Factors—

(7) *Water*—It has got both disintegrating and decomposing power. Water is ordinarily a good solvent. It can dissolve many mineral substances. *Leaching* is the term which is used for the removal of soluble substances in solution by percolating water. Chemical combination with water is called *hydration*. Hydration is often accompanied by slight increase in volume. This exerts additional pressure and acts like wedge similar to a certain extent to the frost action.

Iron minerals are easily attacked with water and the result is the formation of iron-hydroxide, limonite, $2Fe_2O_3$, $3H_2O$. Limestone is not attacked by pure water but if the water contains CO_2 in solution then it becomes a good solvent of limestone. $CaCO_3 + H_2O + CO_2 = Ca(HCO_3)_2$. Its effect in limestone region has been separately dealt in the chapter on underground water (Chapter-VIII). Quartz is a fairly resisting mineral but it is soluble in alkaline water. Muscovite resists the decomposing attack by water to a great extent. Felspars are easily attacked and clay minerals are formed by the decomposition of it.

$K_2O, Al_2O_3. 6SiO_2 + H_2O + CO_2$
(Orthoclase)

$$=K_2CO_3+Al_2O_3,2SiO_2, 2H_2O+K_2CO_3+4SiO_2$$
(Kaolin) (Sand).

K_2CO_3 is removed in solution. Water brings about another important change, *hydrolysis*, which has also considerable effect in rock weathering.

(8) *Carbon dioxide*—Chemical combination with carbon dioxide is called *carbonation*. Its importance in the solution of limestone and production of clay from felspars has already been stated. Indirectly it supports vegetation which produces humus and thereby brings chemical weathering.

(9) *Oxygen*—Chemical combination with oxygen is called *oxidation*. Iron minerals show conspicuous colour changes by oxidation. Combination with water and oxides produces hydroxides of various elements and then they are often leached out.

The chemical agents act quite near the suface. Their effects are lessened as the depth increases. This is because dissolved substances which increase the dissolving power of the solution are removed by the interaction with other substances at quite shallow depth.

All the physical, biological and chemical agents are operating from a very remote time of the earth's history Their cumulative effect is to wear down high lands. Had there been no other forces operating in the opposite direction, all mounttains and other high areas on the earth's surface would have been reduced to flat low lands. Commonly the physical, biological and chemical factors help each other. So also the disintegrating agents help the decomposing agents and vice versa.

Importance of the Atmosphere in the Weathering of Rocks :

All the above factors of weathering excepting the action of gravity are influenced directly or indirectly by the atmosphere. Principally it consists of a mixture of several gases like N_2, O_2, CO_2 and moisture. The moisture content is a very important factor to be considered. It brings about rain and snow which feed rivers and glaciers. The importance of rivers and glaciers as geological agents is supreme and has been dealt in later pages. Precipitated water produces both disintegrating and decomposing effects on rocks.

Atmosphere also distributes heat and therefore influences effects of temperature changes.

Precipitation and CO_2 largely determine the vegetation at a place. Animals and vegetation thrive one on the other. Indirectly therefore atmosphere influences weathering of rocks through animals and plants.

Water comes from the precipitation of the moisture and the melting of snow. Snow also comes from the atmospheric moisture. How important is the function of water in disintegrating and decomposing rock masses has already been stated.

Wind is a drift of air. Its work in weathering of rocks is also considerable.

The importance of CO_2 and O_2 in chemical weathering of rocks is quite great and has been already treated. The greater part of the atmosphere is nitrogen. It is transformed into nitric acid by means of bacteria and lightning. Nitric acid is a good dissolving agent and brings about a great deal of weathering in rocks. Nitrates are also very helpful for plant growth.

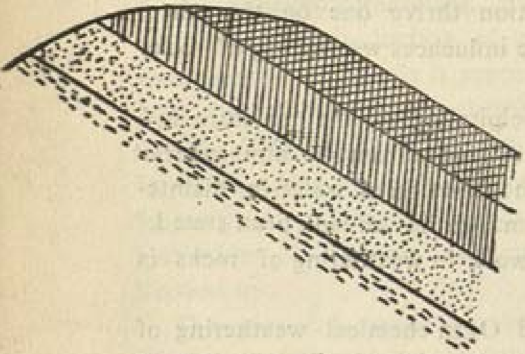
It is therefore clear how great is the importance of the atmosphere in the weathering of rocks.

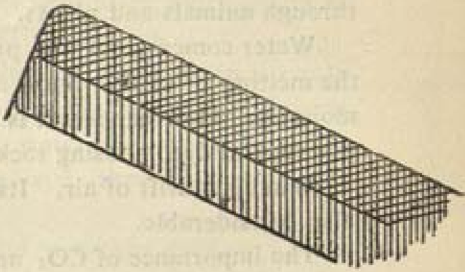
Some Erosional Features :

Badland—It is a peculiar type of land which is developed in semi-arid regions due to pronounced erosion, by running water. Such areas are very intricately traversed by gullies. This develops mostly on argillaceous rocks. In India such badlands or ravine lands are found in Agra, Mathura, Etawah etc. areas of the Jamuna and the Chambal basins, in the Siwalik regions and deforested regions of the Damodar valley.

Escarpment—In inclined beds with harder rocks overlying soft ones the more resisting hard rocks are eroded at a very slow rate whereas the underlying soft ones are eroded much more easily. The result is the formation of steep slope on one side and a gentle slope on the other. The steep side is called an escarpment. (PL—12).

Hogbacks—These are ridge-like stuctures with high steep sides on two sides formed by harder rocks in an inclinded series of beds.



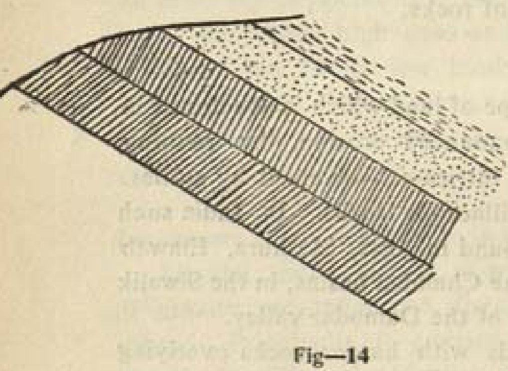


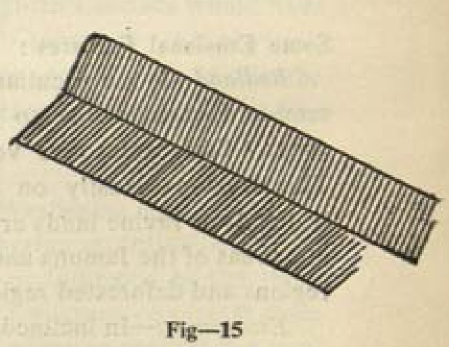
Fig—12
Initially

Hogback

Fig—13
Finally

Cuesta—It is a Spanish term used to indicate a peculiar structure produced as a result of erosion on an inclined series of alternating hard and soft beds. It has on one side an escarpment but the other side is very gently sloping.





Fig—14
Initially

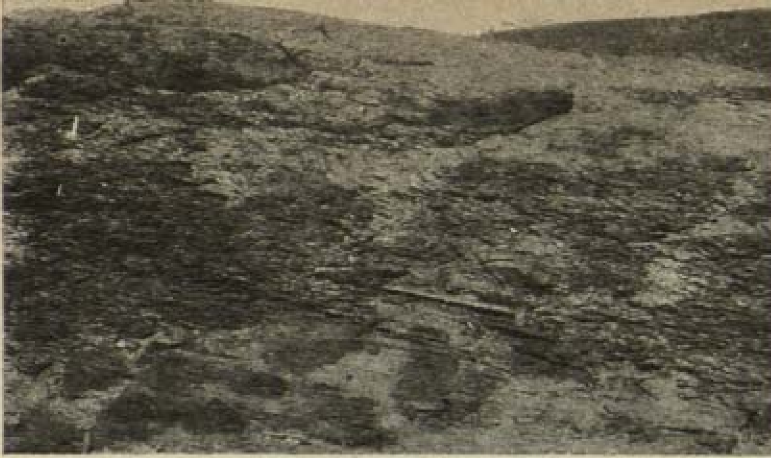
Cuesta

Fig—15
Finally

Mesa—On horizontal beds with an overlying bed of hard rock, the effect of erosion is the production of a table-land

Pl.—6 Current bedding in Barakar Sandstone

(By courtesy, Director, G.S.I.)



Pl.—7 An unconformity marked by a conglomerate bed in Hornblende Schist, East of Gandemasa, Singhbhum.

(By Courtesy, Director, G.S I.)

Pl.—8 Streaky Gneiss

(By courtesy, Director (G.S.I.)

with steep slopes on surrounding sides. Such a terrace-like feature is called a mesa. The word mesa is a Spanish term meaning a table.

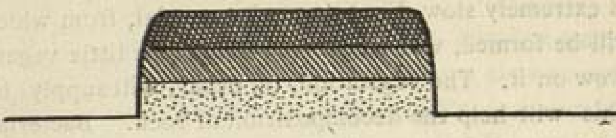


Fig. 16
Mesa

Butte—With continued erosion mesas become flat-topped hills with terrace-like aspect. Such hillocks are called buttes (PL—13).

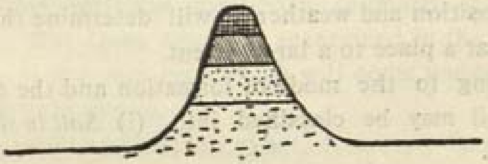


Fig 17
Butte

Soil :—

Bed rock—It is the hard rock mass underlying the loose rock materials and the soil.

Mantle—The mass of loose rock materials that covers the bed rock of an area is called the mantle or regolith. Mantle may be of two kinds—*residual mantle* which has been formed at the same place, and the other *transported mantle* that has been formed from rock particles carried from other places.

Soil—If in an area we go on digging we shall first of all get a region of very loose materials which supports the vegetation. This part is called the *top-soil*. Below this zone we will be getting more and more angular rock fragments. This zone is lighter compared to the above zone and is less weathered. This zone is called the *sub-soil*. Below this zone we will get the hard bed rock. The soil may be or may not be derived from the underlying bed rocks. If it is not formed at the same place, the soil is called *sedentary soil.* If it is formed from transported rock debris it is called *transported soil.*

Development of a mature soil which can support vegetation is extremely slow. First the rock material, from which the soil will be formed, will be decomposed and a little vegetation will grow on it. The vegetation, on decay, will supply humus and this will help the decomposition of rock. Bacteria will also help. As the process will go on, ultimately a thin deposit of soil will be formed, upon which will thrive more vegetation. Gradual decomposition of the rock and leaching of soluble material will increase the breadth of the soil zone. Abundance of rain water greatly helps the formation of soil by decomposing the rock as well as by supporting vegetation. Climate, rock composition and weathering will determine the character of the soil at a place to a large extent.

According to the mode of formation and the agencies involved, soil may be classified into (i) *Soil in situ* and (ii) *Drifted soil.*

They are further subdivided in the following ways :—

(i) Soil in situ :—

(a) *Residual soil*—It is that type of soil which has been formed at the same place where it is found. It shows clear connection with the parent rock mass below. More or less the same composition is present in the soil as well as in the bed rock.

(b) *Cumulose soil*—This is an organic type of soil. It is formed mostly by the accumulation of organic matter like peat. Mineral matter is subordinate in importance. They are best formed under marshy condition, in lakes, estuaries, dried up river beds, deltaic regions and similar water-logged areas.

(ii) Drifted soil —

(c) *Colluvial soil*—These are formed of materials accumulated at the base of a steep-sided mountain by the action of gravity. The soil, thus produced, is very meagre and is stony. It supports very little of vegetation excepting some mountain plants.

(d) *Alluvial soil*—It is formed of the alluvium brought by rivers. It is a very fertile soil. The soil of the Indo-Gangetic Plain is of this nature. It shows slight stratification sometimes.

(e) *Glacial soil*—Boulder clay or till forms at times good soil. The peculiarity of glacial soil is that it shows practically no connection with the rock below in its rock composition because the materials have been transported from other places by moving glaciers. The rock fragments have been ground very fine by glacial abrasion. There is very little of decomposed material. The felspars are practically undecomposed. The individual particles, though fine, are somewhat angular instead of being rounded as in the alluvial soil.

(f) *Æolian soil*—The wind-borne sediments at times form scanty soil. The loess deposits, mentioned in the chapter on wind action, is the only type which will come under this head. Loess soil is very fertile.

(g) *Lacustrine soil*—This type of soil is formed in the lakes. The river-borne and glacier-borne sediments collect in the lake basins and form soil at a later stage when the lakes have been dried up. Such soils are generally rich in organic matter and when the area has been well drained they form good soils.

(h) *Marine soil*—This type of soil is formed from sediments deposited on the coastal region or on the continental shelf zone of the sea and later uplifted. Such soils show stratification. They are mainly sandy and coarse-grained.

(i) *Volcanic soil*—This is the type of soil which is formed from pyroclastic materials and lavas erupted during volcanic eruptions. This type of soil is very fertile and is widely cultivated inspite of the danger of sudden eruption.

According to texture, composition, porosity, permeability, moisture-retaining capacity, content of organic matter and agricultural use, soils are also divided into several types such as follows :—

(1) *Sandy soil*—This type contains abundant sandy particles. Quartz is predominant. There is very little of clay

material. It is highly porous and has a very litte water-retaining capacity. It is not very suitable for agricultural purposes because constant watering is then necessary.

(2) *Loamy soil*—This type contains sand and clay materials, more or less in equal proportion. It is very suitable for agricultural purposes.

(3) *Clayey soil*—In this type clay minerals predominate. It has a very high water-retaining capacity. Clayey soil containing much limestone is called *marly soil*.

(4) *Black soil or Chernozem*—This is a black type of clayey soil which is generally formed from the decomposition of basalts and some other basic types of rocks. They contain a high percentage of oxides of aluminium, calcium, magnesium and a rather variable percentage of humus. The colour of the Indian black soil is due to iron compounds, whereas that of the Russian chernozem is due to the humus content. The iron and humus determine the black colour of the soil. It swells up when wet and has a high water-retaining capacity. This soil is highly fertile and is very suitable for cotton plants.

(5) *Peat soil*—This type of soil contains very little of clayey matter but mostly the decomposition products of vegetable matter. It has a good water-retaining capacity. If well drained and properly manured it forms a good productive ground for such crops as onion etc.

(6) *Podsol*—It is a gray type soil in which there is very little of iron compounds and humus. It is generally sandy and not fertile.

(7) *Lateritic soil*—This is a type of brownish soil which is composed mainly of the hydroxides of iron, aluminium and subordinately of the hydrated oxide of manganese. At places the percentage of titanium oxide becomes considerable. There is very little of silica, magnesium, calcium, and the alkali materials, which have been leached out from the parent material. There is very little of humus also. Basalts generally but granites and gneisses also, give rise to lateritic soil under peculiar tropical monsoonic climate with seasonal rainfall and alternating drought. This type has got very little

agricultural value as it lacks in the salt content and humus.

Indian Soil Types :—

Indian soils specially in the Extra-Peninsular and the Indo-Gangetic Plain are quite young and have not attained the mature stage of development. They are mostly post-Pleistocene in their formation and the soil forming processes have not got sufficient time to work upon them. In the Extra-Peninsular region, the soil is very scanty. At the base of mountains or in flat river valleys there may be a very meagre deposit of soil. The soils are mostly sandy. In the foot-hill regions of the Himalayas peat and loamy soils are found. At some places in Kashmir soils derived from glacial sediments are also found.

In the Indo-Gangetic Plain soils are mostly alluvial. In the northern part soils are sandy but towards the mouth of the rivers soils are loamy and very fertile. Near the mouths of the rivers in the deltaic regions soils are peaty and rich in humus. A large part of the Punjab (I) and Rajasthan is covered under aeolian deposits and is devoid of soil. At some places in Western Rajasthan *alkaline soil* called *reh* or *kallar* is found. Concretionary deposits called *kankar* are also found in U.P. and Bihar.

In the Peninsular part soil has attained maturity to some extent. *Regur* or *black cotton soil* is a very remarkable type of soil which covers practically the whole of Bombay State. This black cotton soil has been derived from the decomposition of the Deccan basalts. It is highly fertile and has been cultivated for years together without manuring. This is because of the high percentage of the oxides of calcium, magnesium etc. The difficulty with this type of soil is that it becomes very hard after it has been moistened with water and then develops cracks on it on drying. It is then very difficult to plough such soils.

The eastern part of the Peninsular India, specially the Madras State, shows in some parts red or brown soils. The colour is due to the iron content. Unless properly manured they have little agricultural value.

Lateritic soils are found in places of West Bengal, Bihar, Orissa, M. P. and Assam. They are seen on highlands generally. There are two types of it—*high level laterite* and the other *low level laterite*. The former type is formed at an altitude greater than 2000 ft. whereas the latter is formed at lower altitude even in some coastal areas of Madras State.

Sandy soils occur in the coastal regions. In the western coast there is a very narrow coastal area whereas in the eastern part a considerably wide coastal region has been developed. The mouths of some of the rivers have deltaic deposits mostly of silt with sometimes some organic matter.

Soil Erosion and Protective Measures :—

Huge quantity of valuable soil is eroded by running water and wind. The preservation of soil is a problem and this is more so in agricultural countries like India. Soil erosion is done in two ways—(i) *sheet erosion* which is done by surface washing or deflation by wind, and (ii) *gully erosion* which is done by running water by cutting channels.

The main cause of soil erosion is the destruction of forests that cover the land. Over-grazing by pasturing animals also destroys the protective cover of vegetation. This produces bare dry lands and they fall easy victims to mass-wasting by running water and wind. Vegetation retains moisture in the ground and this moisture acts as binding substance in the rock particles. Destruction of the vegetation therefore removes the protective layer from the land. As a consequence the land is easily eroded away. The speed of soil erosion varies from place to place with the nature of the soil, amount of rain-fall and covering vegetation.

Conservation of soil is therefore a crying need. It can be achieved by preserving the forests, controlling grazing, by proper planting of crops, by terracing and levelling the ground so as to retard the speed of running water and by storing sufficient water in the soil so as to check deflation by wind. The idea of all these processes is to preserve the valuable top soil.

CHAPTER VI

RIVERS

Before beginning with the subject proper, the following terms should be learnt, as these will be frequently used in later pages of this chapter.

Canyon and gorge—These two term denote steep-walled deep narrow river valleys. As for example the Grand Canyon of the Colorado in Arizona which has a length of 200 miles, breadth of 10 miles and depth of more than 5000 ft. in places (average depth 3400 ft.) and which has been excavated out of a plateau mass of nearly horizontal sedimentary beds of Paleozoic age underlain by some Pre-Cambrian and Archaean rocks. The Indus Gorge near Gilgit has a depth of 17000 ft.

Gradient—It indicates the inclination of the surface or the surface slope of an area. It is expressed as 1 in 100 etc.

Run off—It is the part of the precipitation which flows through rivers. It is of two types—on *surface* or *immediate run off* indicating the part which flows over the land surface and another *ground water* or *delayed run off* which comes to the surface again after percolating underground. It has been estimated that nearly 9000 cubic miles of water flow to the sea as run off in a year.

Load—It means the amount of rock material carried by a river either in solution or in suspension.

Base level of erosion—It is the mean sea level produced inland and marks the ultimate limit of down-cutting by a river. It is also called *O-level*.

Flood Plain—It is the area on both sides of a river which has been formed by flood-time river deposits and over which the river spreads in times of flood.

Development of a River System—Every tract of land on the surface of the earth is marked by irregularities. As a result when rain falls or glacier melts or spring water sprouts or a

Pl.—9
Spheroidal weathering of basalt, Bombay State.

Pl.—10
Weathering of granites. Lunavada
(By courtesy, Director, G.S.I.)

Pl.—11

Landslide in Quartzites, north of Dhasan Bazar, Nepal

(By courtesy, Director, G.S.I)

Pl.—12

Kaimur scarp, Son valley

(By courtesy, Director, G.S.I.)

lake overflows upon such areas, the water flows outward and downward taking the shortest route. Thus little gutters are formed. Such gutters are miniature streams and perform the same type of action though on a small scale. The gutters thus formed will converge at a later period downward and their union forms streamlets. Several such streamlets unite at still downward regions and form streams In this way a complex branching type of drainage system will be developed upon the area. Rivers are bigger bodies formed by the union of several steams.

Several distinct stages can be seen in the development of a river. They are the initial, the youth, the mature and the old stages.

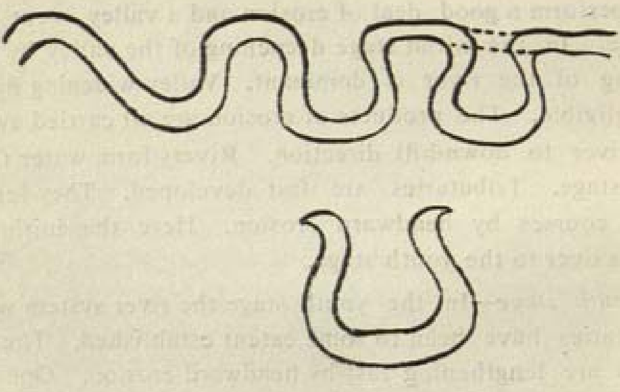
Initial stage—Rivers generally originate from mountainous regions where gradient and supply of water, either in the form of rain-water or in the form of melt water, is considerable. In the initial stage of a river, several gutters will combine to form a stream. Streams will unite to form a river. The gradient is here quite high, as a result of which the rivers can perform a good deal of erosion and a valley is cut in due course. In the initial stage deepening of the valley by down-cutting of the river is dominant. Valley widening by river is negligible. The products of erosion are all carried away by the river to down-hill direction. Rivers form water falls at this stage. Tributaries are fast developed. They lengthen their courses by headward erosion. Here the initial stage passes over to the youth stage.

Youth stage—In the youth stage the river system with its tributaries have been to some extent established. The tributaries are lengthening fast by headward erosion. One of the noted effects of headward erosion is the *river capture* or *river piracy*.

Suppose two rivers were initially flowing more of less at some inclination to each other. One river was lengthening its valley by headward erosion. Ultimately it will reach the other river and if the first river has got a greater gradient then the course of the second river will be diverted and the water of it will now be drained through the channel of the first river. This phenomenon is known as river capture or river piracy. The point where the course of the second river is diverted is known as the *elbow of capture*. The captured river is called the *misfit* and the abandoned part of the channel through which no water flows is called the *wind gap*.

Indian examples of river capture are furnished by the Arun (a tributary to the river Koshi) and by the Bhagirathi of the Ganges.

Mature stage—In this stage valley widening has begun by lateral cutting and a complex branching system of rivers will be developed. The river has now come to the plain or is flowing over a more or less flat country. The drop in gradient decreases the velocity of the river as a consequence of which the erosive and the transporting powers are also diminished. Most of the load of sediments is deposited at the



Fig—18
Ox-bow lake and meandering river.

foot-hill regions producing *fans* or *alluvial cones*. Rocks formed from fan deposits are called *fanglomerates*.

From this time the river flows with a diminished velocity. Slight irregularities in its path deflect the course of the steam. The river moves in a zigzag way. The rivers are then said to be *meandering*.

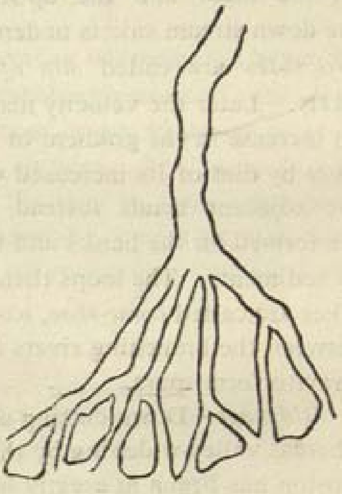
When the velocity of the river is checked very much and the river is flowing with a more sluggish rate, the loops of the meanders become more pronounced. At the inner and up-stream side of the bends the velocity of the river is slow, whereas at the outer and down-stream side the velocity is comperatively great. The result is that a thin deposit of river-borne sediments with an outward sloping side is formed on the inner and the up-stream side, wheras the outer and the down-stream side is undercut by the river current. These two sides are called *silp off slope and under cut side* respectively. Later the velocity may again be increased by either an increase in the gradient or an increase in the flow. The river by dint of its increased velocity takes a short cut across the adjacent bends instead of flowing through it. Deposits are formed on the banks and the mouth of the bend is blocked by sediments. The loops then turn to be so many lakes. These lakes are called *horse-shoe*, *ox-bow* or *cut-off* lakes. The divides between the branching rivers have now been greatly eroded away to form spurs.

Old stage—Down-cutting of the river is now diminished whereas valley-widening by the processes of weathering and erosion has begun at greatly increased rate. Down-cutting has already reduced the gradient considerably and stops at the base level of erosion which is the mean sea level produced inland. Erosion by river is confined to the lateral cutting as a result of which the river is widened more and more. At last during the late stage of development the river valley becomes nearly flat.

In the old stage the river valley has become practically flat The river is then flowing very slowly. Frequently the river is over-flooded and builds up flood plains on both sides. The flood plains are marked by ridges formed by flood-time deposits which are called *natural levees*.

The initial irregular surface has become practically flat at the old stage of river development. This plain land produced by the river action is called *peneplain*. Though nearly smooth, here and there some mounds or small hillocks of hard rocks still persist. These hillocks are called *monadnocks* (after the name of Mt. Monadnock formed in this way in New Hampshire in U.S.A.).

At the last stage the river falls to the sea or to a lake. Rarely it may terminat e in a marshy land or in a desert. When it meets the sea or a lake, a river may form a *delta*. Deltas are triangular structure built by river deposits. The name is because they resemble the Greek lettter △ (delta). In a deltaic deposit three distinct layers are seen. The ground layer is formed of finer sediments and is called *bottom set* bed. After this is the middle layer consisting of coarser material. This layer is called *fore set bed*. The upper layer is formed of a mixture of coarse and fine material and is called *top set bed*.



Fig—19
Delta

The formation of a delta starts at the mouth of a river. where the river meets with calm expanse of a sea or a lake The ideal condition for the growth of a delta is that the sea or the lake must be tideless and the velocity of the river will also be sluggish and there will be a sufficient load of sediments in the river. Under these conditions (all of which are seldom present) the load of sediments is deposited at the mouth of the river and gradually the deposits come over water to form a delta. Deltaic structure obstructs the flow of the river and the river divides itself into so many branches to fall to the sea. The branches are called *distributaries*. The part of Southern Bengal to the east of the Hooghly River up to the River Padma is the famous delta of the Ganges.

Such a developmental course is followed by each river. Later with the uplift of the source region, the gradient may again be increased. The river will then begin down-cutting and valley deepening and the whole course will be repeated. Such a cycle of processes from the initial or mountain stage to the old or delatic stage is called a *fluvial cycle*. Such cycles recur one after another. Commonly one cycle is not fully completed because of disturbing earth movements.

Development of a River Valley :—

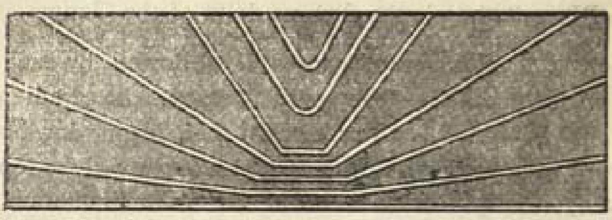
Each river occupies a valley which it has excavated, though sometimes rivers occupy valleys which are pre-exiting. The later type of valley is modified by the river action.

Development of a river valley depends upon several factors such as climate, composition of the bed rock and the surface relief.

Initially the concentration of rain water or melt water in to the shortest routes down-hill causes the formation of little valleys which are occupied by rivulets. It may also be initiated by the presence of several pot-holes more or less in a linear tract or by the retreat of a water-fall. More and more run off through these little valleys enlarges them. They widen a little but are deepened much more as in the earlier stages of development the down-cutting by rivers preponderates over lateral-cutting.

The valleys in the young stages are lengthened headward by head erosion. Perchance some other rivers may be captured in this process of head erosion. This will add to increase the discharge as a result of which more and more erosion, mostly in the form of down-cutting, will ensue. Down-cutting produces deep gorges but there is a limit to the process of down-cutting. Commonly it stops when the base level of erosion is reached at a late stage.

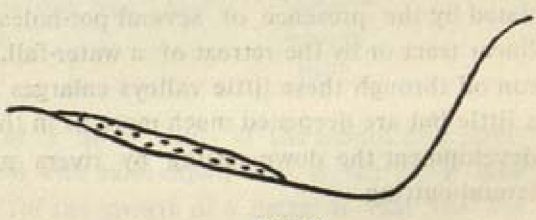
The young valley has a V shaped cross-section. The V



Fig—20
Valley widening

widens out as the valley reaches maturity more and more. Lateral cutting by the river erodes the valley sides at a faster rate than that by valley-deepening. This brings more and more flatness to the valley floor.

The gradient has decreased considerably by this time. Considerable amount of sediments has been formed and the river has to use nearly all its energy in transporting the load. This reduces the velocity of the river. The course of the sluggish river is thrown to the sides by the irregularities on the valley floor. The river is now meandering on the valley. In the first stage the valley of a meandering river is narrow. At the inner and up-stream side the velocity of the river is slow. The water dashes directly on the outer and the down-stream side causing it to be eroded



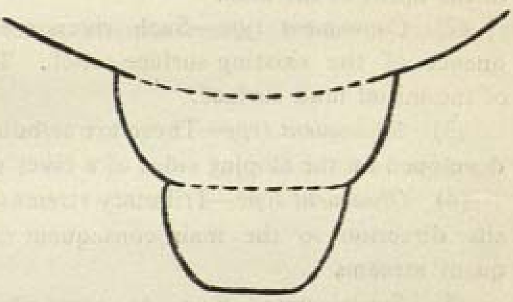
Fig—21
Slip off slope and under cut side

quickly. The water here is the deepest and side is also steeper compared to the inner and up-stream side. This causes the deposition of sediments on the inner and up-stream side and considerable erosion on the other side. The result is the formation of *slip off slope* on the inner side and an *under cut side* on the outer.

Gradually the projections of the curves on the valley are eroded away and the valley floor is widened. This produces finally a continuous valley with a more or less flat floor containing the meandering river. The width of the valley is much greater than the width of the river here. Such a valley floor is called *strath.*

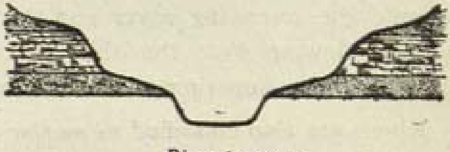
In the later stages of development the valley continues to widen but with a slower rate. Down-cutting has practically stopped. The valley has become nearly a plain with very gently sloping sides. The development is now complete. The valley has become old.

Later uplift in the source region causing increase in the gradient may increase the velocity of the river. Down-cutting then again begins and more or less the same cycle, as mentioned above, will follow. The rejuvination of a river may arrest the valley development at any stage and the earlier stages will begin with it. This produces a step-like aspect in the river valley and the number of such cycles of development processes can be inferred from these steps. (PL-14)



Fig—22
River valley showing rejuvinations

These step-like features are however to be differentiated by field observation from the river or rock terraces that are produced by differential erosion of soft and hard rocks composing the bed rock of a river valley.



River terraces
Fig—23

The rejuvination of a river in the meandering stage produces more deepening of the valley with the still maintenance of the winding course. Such gorges are called *incised meanders*. The bends of the incised meanders are seperated by wall-like projections which are eroded away at a later stage.

Types of Rivers—From the point of development and origin several distinct types of rivers can be recognised. They are :—

(1) *Antecedent type*—Such rivers were existing before the surface relief was impressed upon the area as for example, the Indus, the Sutlej and the Brahmaputra. These Himalayan rivers have cut transverse gorges across the mountains. The uplift of the Himalayas increased their gradients and their increased erosive action was able to maintain their course across the mountains. Such rivers are able to maintain their original course inspite of later crustal deformation resulting in the uplift of the area.

(2) *Consequent type*—Such rivers are formed as a consequence of the existing surface relief. They follow the slope of the initial land surface.

(3) *Subsequent type*—These are tributary rivers which are developed on the sloping sides of a river valley.

(4) *Obsequent type*—Tributary streams flowing in an opposite direction to the main consequent rivers are called obsequent streams.

(5) *Superimposed type*—At some places old rocks may be covered under a sheet of new deposits. Any river that will be developed on such an area will follow the surface relief of the overlying cover and will not have any relation with the older rocks lying below. Gradual erosion by the river will remove the overlying cover and the river with its tributaries will be flowing over the older rocks below. The rivers are then said to be superimposed on the older rocks below.

Rivers are also classified as *marine* or *continental* depending on whether they do or they do not enter the sea, and as *longitudinal* or *transverse* depending on their courses being parallel or transverse to the direction of the folding of a mountain or any such long structure.

Pl.—13 Butte of Rewa Shales, Bhainsrorgarh. *(By courtesy, Director, G.S.I.)*

Pl.—14 Three river terraces as seen in Bunji oasis. *(By courtesy, Director, G.S.I.)*

Pl.—15
Gorge of the Zozila (*By courtesy, Director, G.S.I.*)

Geological Action of Rivers and the Associated Forms :—

River erosion :—

Erosion by river is done principally in four ways. These are—(1) *Hydraulic action*, (2) *Corrasion*, (3) *Attrition* and (4) *Corrosion*.

(1) *Hydraulic action*—Forces inherent in the flow of running water can perform a good deal of mechanical erosion. It can loosen fragments of the rock from the river bed and the sides, and remove them along with other loose materials. This process is clearly illustrated by a heavy shower of rain in a ploughed field.

(2) *Corrasion or abrasion*—It means the mechanical abrasion of the rocks of the river bed and the sides. The current of the river carries a considerable quantity of rock waste as the load. Fragments of the rocks are always striking against the bed and the sides of the river valley. The result is that rocks are getting eroded and the products of abrasion are carried by the river current. Fresh exposures are thereby made and the rocks are more and more eroded away in this way. The rock wastes serve as the tools of destruction for the river current.

The formation of *pot-holes* is one of the illustrations of this process. These are more or less rounded or ellipsoidal hollows in the form of vertical shafts. These are made on the river beds by the mechanical abrasion done by revolving rock fragments caught up in whirling eddies of river currents. When the revolving rock fragments are worn down, near ones take their place and the deepening of the pot-hole goes on so long as the river has got sufficient current strength.

(3) *Attrition*—It is the mechanical wear done on the transported rock fragments themselves. During corrasion and transit, these fragments often collide among themselves, the bed rock and sides. As a result they are worn down. Bigger boulders are worn down gradually and cobbles or pebbles are worn down to sands or silts.

(4) *Corrosion or solution*—It means the chemical erosion by river water. The dissolving power of the river water is increased by the presence of some aiding substances like alkali

matter and some gases like carbon dioxide etc. The solubility of the materials composing the bed rocks also determines the part of the corrosion by river water.

Factors influencing River Erosion :—

(1) *Surface relief*—This determines the gradient upon which the velocity and the erosive power of a river depend.

(2) *Climate*—It determines the precipitation and finally the volume and the velocity of the river. Upon the velocity depends the erosive power of a river. It has been estimated that velocity varies as the square of the abrasive power i.e. if the velocity be doubled, the erosive power will increase four times.

(3) *Nature of the bed rock*—If the rocks be soft, erosion will be maximum. River water meets with little difficulty in loosening fragments of such rocks whereas if the rock be hard it will be difficult to erode it and consequently river erosion will be checked to a very great extent. The solubility of the materials composing the bed rock also determines the rate of river erosion. If the bed rock be composed of materials which are easily soluble, then the river can perform a good deal of erosion when flowing over such a land. On the other hand if the bed rock be composed of materials which are difficultly soluble, then the river erosion will be minimum, other factors remaining equal. In the case of sedimentary and metamorphic rocks, the layering is also an important factor. Horizontally layered rocks are more easily eroded away than the vertical ones. In the case of inclined beds, if the inclination be in the same direction as the river flow, then erosion will be greater than when the inclination of the beds is in the opposite direction to the river flow.

(4) *Presence of joints and fissures in the bed rock*—Presence of good many fissures and joints in the bed rock facilitates erosion because water can then penetrate to a great depth and consequently a greater area will be exposed to both the mechanical and chemical erosion by the river water.

(5) *Hardness of the transported materials*—As already pointed out the fragments in transit serve as tools of destruction in the case of river erosion. If these fragments be of hard material, mechanical erosion will be maximum. It is obvious because soft materials can do very little erosion as they are likely to be worn down very easily.

(6) *Dissolving power of the river water*—This necessitates the presence of some dissolved materials and gases in river water. Though ordinarily water is a good solvent, its dissolving power is more increased by the presence of some suitable materials in solution with it.

(7) *Nature of the river*—The velocity of a river in a deep narrow channel is greater than that in a broad channel of shallow depth because of greater friction from greater area in the latter case. As the erosive power of a river varies with the velocity, river erosion will be more pronounced with a deep narrow river than with a broad shallow one. The velocity is also dependent on the gradient. The volume of a river also determines to a large extent the velocity. Gradient and the form of the channel being equal, the velocity varies with the volume. It has been estimated that a river with eight times larger volume will flow with a velocity doubly swifter. This explains why a river is more destructive in times of flood. Rivers which are subject to great variations in velocity and volume can perform more erosion than those which are more or less uniform.

River Transport :—

The products of erosion are carried by the current of the river to other places. Rivers transport not only the products of their own erosion, but to the load are also added materials of other mass-wasting processes. Materials from landslides slumping, avalanches, ground water and wind-borne sediments are also largely transported by rivers. Rivers are the most important transporting agent in nature. What a large quantity of materials is transported by rivers can be thought of from the following figures of silt-carrying capacity of the

Ganges, the Brahmaputra and the Indus. The Ganges carries 90,000 tons, the Brahmaputra over 1,000,000 tons and the Indus 1,000,000 tons of silt per day.

Transport of rock materials by rivers is effected in two ways—one mechanically and the other in solution. Mechanical transport of materials by rivers is influenced by three factors—(1) velocity of the current, (2) nature of the river current and (3) density of rock materials to be transported and buoyancy due to river water.

(1) *Velocity*—Transporting power of a river varies directly as the sixth power of its velocity, that is when the velocity is doubled, the transporting power becomes 64 times increased. This holds good in the case of coarse materials only and not in the case of finer products.

(2) *Nature of the river current*—Suspended fine particles are very easily carried away by river current. The heavier ones, resting on the bottom can be to some extent pushed along with the forward moving currents. They generally require to be lifted before they can be carried forward. At favourable places the whirling currents can lift the particles but this is not the case everywhere. With slight change in position the particles can be pushed further. River channel has sloping sides. This imparts a tendency to the sediments on the sides to move to the central region by the force of gravity. Irregularities of the bed of the river create many changes in directions of the currents. Moreover the velocity is maximum at the central region because of less friction here. These factors cause, every now and then, some changes in the positions of the materials lying at the bottom. Sometimes they are lifted up even, thus facilitating easy transport.

(3) *Density of the rock materials and the buoyancy due to river water*—Every object loses apparently a part of its weight when immersed in water. Thus it is easier to move a full pitcher under water than to lift it above water. In the case of solid materials those with low sp. gr. can remain suspended easily and hence can be carried to greater distances. Heavier ones

collect at the bottom but even then they are made apparently lighter under water because of buoyancy. This lessens the burden on the current. Had there been no such property of water, the transport of the materials by rivers would have been much more difficult. The presence of salts in river water increases the density of it which in its turn produces more buoyancy thus facilitating the transporting action of rivers.

Materials carried in Solution—Apart from the mechanically carried sediments, a huge quantity of materials is carried in solution. This quantity comes from the solution of the soluble materials of the bed-rock over which the river flows together with the amount contributed by the underground and rain water. These materials include carbonates of calcium and magnesium, sulphates of calcium, magnesium, potassium and sodium and the like. The contribution of these salts to the seas by rivers is increasing the salinity of the sea water every y ear.

River Deposition :—

Where the velocity of the river is checked, deposition of the sediments takes place. Obstructions to the velocity are offered by the irregularities in the river course and more specially at the curves. It has already been seen in the case of meandering rivers that the deposition takes place at the inner and up-stream sides. Such places are favourable sites for deposition and prospectors have specially to examine such bends for placer deposits like gold, cassiterite, wolfram etc.

All the factors, which tend to diminish the velocity of rivers influence the deposition of sediments. Loss of gradient is an important factor. It has already been discussed in the case of development of rivers that the plain stage of a river is mainly marked by deposition. This is because of the fact that the gradient here is considerably less than that in the mountain stage. It has also been stated that where a river abruptly falls on the plain from a mountain, deposition at once takes place resulting in the formation of alluvial cones and fans. Such depositional features are so named because of their resemblances to cones and fans. In the case of fans the vertex is at the place where the river falls on the plain. Its thickness is maximum at this place and it widens and thins out at greater distance. The union of several such fans makes a more or less continuous plain in front of the mountain. Such plains are called *piedmont alluvial plains.* If the water is absorbed by sediments, the deposits can not spread out and in that case a more or less conical structure is formed which is called an *alluvial cone.*

Loss of volume resulting in the decrease in velocity also causes deposition. This is specially manifested after floods. During flood time a river does considerable damage by means of its sudden increase in volume but when the flood subsides, the volume of the river gets diminished and consequently there occurs a good deal of deposition in the form of alluvial deposits.

Where a river, charged with considerable sediments, meets a tideless sea or a lake, deposition of the sediments takes place and deltas are formed. More or less similar deposition makes bars across the mouths of rivers.

One of the peculiarites of the river-borne deposits is the sorting of the sediments. The heavier and the larger ones do not travel much and are deposited near the source, whereas the lighter and the finer sediments are carried to greater distances.

Graded River and Profile of Equilibrium :—

In the early stages of river development, the gradient is considerable and hence erosion in the form of valley-deepening is more pronounced. Continued down-cutting reduces the gradient and with cosequent loss of velocity, the erosive power is diminished. Then the products of earlier erosion are to be handled also. When a considerable amount of rock waste has been formed, the river has to spend most of its energy in transporting the sediments. Consequently the erosion is diminished. In the mature stage therefore a sort of equilibrium is reached between the erosion on the one hand and the deposition on the other. When there is more erosion than the normal, the gradient becomes less. This reduces the erosive power by diminishing the velocity, and the transporting power is also diminished. This results in deposition of a part of the sedimentary load that the river is carrying. The deposition again builds up the normal gradient at some other place. Thus excess of erosion is immediately compensated by excess of deposition and vice versa. Thus a state of balance is reached between the erosion on the one hand and the deposition on the other. When this is attained the river is called a graded river or is at grade and its profile is then called a profile of equilibrium or a graded profile. At the time of erosion a river is degrading and at the time of deposition the river is aggrading.

Depositional features illustrating the work of rivers include alluvial cones, fans, piedmont alluvial plains, flood plains, natural levees, deltas, bars etc. All these have been described in the previous pages of this chapter.

INDIAN RIVERS

Indian rivers can be divided into two major groups—(i) those of the Peninsula and (ii) those of Extra-Peninsula.

Peninsular Rivers :—

These rivers possess some peculiarities in the fact that majority of them have reached the old stage. They have reached the base level of erosion, and have wide and nearly flat valleys in which they meander sluggishly. In times of heavy showers of rain they become quite full and are often over-flooded causing immense damage to crop and property, thus bringing untold miseries to the people. For the most part of the year, they go on depositing their sedimentary load here and there in their courses.

Most of the Peninsular rivers follow an easternly course. Dr. H. L. Chhibber points to a radial drainage from the central Indian highlands. This is corroborated by the easternly flowing Damodar, by the south-easternly flowing Subarnarekha, by the southernly flowing tributaries of the Godavari like the Wainganga and the Wardha, by the westernly flowing Narbada and the Tapti, and the northernly flowing tributaries of the Jumna like the Chambal, the Betwa and the Ken, and the Son, a tributary to the Ganges.

Among the more southern rivers of the Peninsula an easternly drainage can be seen. With the exception of the Narbada and the Tapti and the small rivers which start from the Western Ghats and fall into the Arabian Sea, all the rivers like the Mahanadi, the Godavari, the Kistna, the North and the South Pennars, the Cauvery etc. follow an easternly course. The Western Ghats serve as their water-shed. This abnormal phenomenon is explained by two assumptions. One of them states that the Deccan Plateau received an easternly tilting at the time of the Himalayan upheaval. Another explanation is that the western half of the continental block, of which the Western Ghats are the backbone, has been faulted and gone under the Arabian Sea. The western coast of the Peninsula is a faulted region undoubtedly and hence the second explanation is more in keeping with the observations. We are therefore getting the rivers east of the Western Ghats, whereas those to the west have been submerged along with that tract containing them.

The westernly flow of the Narbada and the Tapti is explained by the assumption that these rivers are flowing along two fault lines and not in the v alleys cut by them. There are also a good many small rivers following an westernly course which arise from the Western Ghats and fall into the Arabian Sea. These are fed by rain water and become highly torrential during the monsoon periods. Hence they can not build any extensive deltaic deposits at their mouths and except in Gujrat there is a very narrow coastal strip on the west coast of the Peninsula. As a contrast to these the easternly flowing rivers like the Mahanadi, the Godavari etc. have built extensive deltaic deposits at their mouths.

The little southern rivers often make falls and cascades. They have therefore great potentialities as sources of hyhro-electric power. Some of them have already been trapped and schemes for several others are also awaiting execution.

The Extra-Peninsular or The Himalayan Rivers :—

The following peculiarities are to be noted in the case of the Extra-Peninsular rivers.

(1) *Antecedent drainage*—The Himalayan rivers like the Brahmaputra, the Sutlej and the Indus illustrate this type of drainage. These three are amongst the oldest rivers of the region and were in existence much before the main uplift of the Himalayan mountains. The gradual upheaval of the Himalayas was increasing their gradients. As a result their erosive powers were also increasing and hence they were able to maintain their courses right across the Himalayan chain. These three rivers rise in the Tibetan side beyond the high mountain peaks of the Himalayas.

(2) *Transverse gorges*—These have been cut across the Himalayan chain of mountains by some of the Extra-Peninsular rivers. They are deep chasms and run across the main mountain chains. The most prominent one is the Indus gorge near Gilgit which has a depth of 17,000 ft. Apart from their formation due to the down-cutting by rivers several other explanations have been put forward to account for their origin. It is believed by some that they have been formed by the widening of fault planes by rivers flowing through them Another idea is that they have been formed by the sudden escape of dammed up rivers. They may also be due to head erosion specially in the case of smaller rivers.

(3) *Head erosion*—Many of the rivers of the Himalayan region have cut their valleys back by headward erosion and some of them have captured other rivers flowing through different channels and in different directions. Examples of such river capture are furnished by the tributary Arun of the Kosi river, the Bhagirathi of the Ganges and others.

There are twenty three principal rivers belonging to three major river systems in the Extra-Peninsular region. They are :—

The *Brahmaputra system* consisting of the Brahmaputra, the Luhit, the Dibang, the Subansiri, the Manas, the Sankosh, the Raidak and the Teesta, the *Ganges system* consisting of the Kosi, the Bhagmati, the Rapti, the Gandak, the Karnali (the Gogra on the Plains), the Ramganga, the Khoh, the Kali (or the Sarda), the Jumna and the Ganges and the *Indus system* (mostly flowing through West Pakistan) consisting of the Sutlej (Satadru), the Beas (Vipasa), the Chenab (Chandrabhaga or Asikni), the Jhelum (Vitasta) and the Indus (Sindhu).

Most of the above rivers are fed by the melt water from the Himalayan glaciers and are perennial. Others are fed by rain water and have variable discharges. The mean annual water supply in the rivers of India is nearly 2,300,000 cu. ft. per sec. of which nearly 94 p.c. flows to the sea and the remaining is used in irrigation and agriculture.

Dr. H. L. Chhibber has classified the Extra-Peninsular rivers into four groups.

(1) The Tebetan or the Pre-Himalayan rivers like the Indus, the Sutlej and the Brahmaputra.

(2) The Great Himalayan rivers like the Ganges, the Kali the Gogra, the Gondak, the Teesta etc. They are likely to have been formed just after Middle Miocene i.e. after the second upheaval of the Himalayas.

(3) The Lesser Himalayan rivers such as the Beas, the Ravi, the Chenab, the Jhelum, etc.

(4) The Siwalik rivers such as the Hindan and the Solani near Dehra Dun. They are post-Pliocence in age.

A brief description of the main rivers like the Brahmaputra, the Ganges, the Jumna and the Indus is given here.

The Brahmaputra—In its upper course it is known as the Tsang Po. It rises near the Manasorowar and then flows through the Ladak and the Great Himalayan Ranges for nearly

1000 miles and then takes a turn towards the south at Namcha Barwa in ahe north-east of Assam. It is here known as the Dihang and when it falls on the plains it is called the Brahmaputra. In the recent past this river has changed its course. On the plains it is joined by the Teesta and itself joins the Ganges and forms the Padma to flow into the Bay of Bengal through East Pakistan. Other tributary rivers have been mentioned in the Brahmaputra system of rivers.

The Ganges—The Bhagirathi and the Alakananda are the two main tributary rivers to form the Ganges which join at Devprayag. The Bhagirathi originates from the Gongotri glacier near Kedarnath and is joined by the Jahnavi on its way. The Alakananda has been formed by the union, at Joshimath, of the Dhauli from the Zanskar Range and the Vishnuganga and is also joined by the Pindar from the Nanda Devi and the Mandakini. The Ganges after its union with the Jamuna at Prayag flows over Uttar Pradesh, Bihar and West and East Bengals. Near Murshidabad in West Bengal it is divided into two branches. One of them, the Hooghly River, flows straight to the Bay of Bengal and the other, the Ganges, joins the Brahmaputra to form the Padma and the later flows to the Bay of Bengal (through East Pakistan). The other tributary rivers have been mentioned in the Ganges system of rivers.

The Jumna—It rises from the Jumnotri glacier and is joined by the Tons and the Giri rivers. The Jumna joins the Ganges at Prayag i.e- Allahabad.

The Indus—It rises near the Mount Kailash and is fed by two rivers, the Singi Kampa and the Gartong Chu in its source region. It flows by the Ladak Range and the Nanga Parbat and takes a turn and flows to the plain. In the mountainous region its main tributaries are the Zanskar, the Dras, the Shigar, the Gilgit, the Kabul and the Khurram rivers and on the plain it is joined by the Sutlej and flows over the Punjab and Sind, and then falls to the Arabian Sea. The Sutlej is joined by the the Beas and the Chenab. The Chenab is again joined by the Jhelum and the Ravi. The Indus system of rivers mostly flows through West Pakistan.

WATER-FALLS

When a river falls from a vertical escarpment it forms a water-fall. If the steepness is not pronounced, it is called a rapid. When the water descends over a step-like structure, it is called a cascade, and if the volume of water in a water-fall or a rapid is huge, it is called a cataract.

The origin of water-falls and all the related features is due generally to differential erosion. When a hard rock lies above a soft rock, the soft rock below is eroded with greater rapidity than the hard rock above. As a result the river bed is steepened and a rapid or a water-fall originates. Water-fall may also originate as a result of glaciation, specially in hanging valleys. The damming up of a river for sometime converts the river into a lake and water at its flanks spills out in the form of water-falls below. Vertical movement of parts of the crust due to diastrophic movement or faulting can also produce water-falls. The breaking up of rocks along joint-planes may produce a water-fall, of which the Hundroo Falls in the Ranchi district, Bihar, is an example.

The highest Indian water-falls in Gersoppa of the Swaravati River in N.W. Mysore, consisting of Raja, Rocket, Roarer and Dame Blanche and having a fall of 850 ft. During the monsoon time it becomes very great in volume but during the summer it is reduced considerably. There are also many falls in the Western Ghats. The Shivasamudram Falls of the Cauvery in Madras (300 ft.), the Gokak Falls of the Gokak River in Belgaum in Mysore (180 ft.) the Yenna Falls near Mahabaleshwar in Bombay (600 ft.) the Dhurandhar Falls of the Narbada in the Jubbulpore district in M. P. etc. are noted Indian examples of water-falls. In Bihar, the Hundroo Falls, 27 miles from Ranchi (320 ft.) of which the sheer drop is 200 ft. and width nearly 20 ft., the Jonha Falls (now named

Gautamdhara) 23 miles from Ranchi and the Usri Falls near Giridih are some examples. Beadon, Bishop and Elephant Falls near Shillong in Assam may also be mentioned. Falls are also numerous in the Himalayan region.

CHAPTER VII

OCEANS

The oceans occupy nearly 71 p.c. of the surface area of the earth. They generally taper northwards. The oceans are the major bodies of water and the seas are the minor ones being parts of the oceans which are generally partially surrounded by land areas. A bay is a body of water which is more or less surrounded by land whereas a gulf intrudes further inland. Examples of these are the Indian Ocean, the Arabian Sea, the Bay of Bengal and the Gulf of Siam. All the oceans are connected with one another.

There are six oceans in the world. They are the Pacific, the Atlantic, the Indian, the Mediterranean, the Arctic and the Antarctic. The major ones are described here.

(1) *The Pacific Ocean*—It is the largest as well as the deepest ocean. It nearly occupies half of the earth's surface. It has an average depth of 14,000 ft. This ocean is generally bordered by steep sides and a belt of mountains and volcanoes. The Pacific border is characterised as having a series of deeps. The remaining parts of the ocean is generally flat. There are protruding islands, generally coral islands, built sometimes on the summits of sub-terranean volcanoes.

(2) *The Atlantic Ocean*—It is of lesser extent in area than the Pacific. A prominent ridge, known as the Mid-Atlantic Ridge occurs in the middle part of the Atlantic floor. On either side of this ridge there are deeps. Number of islands in the Atlantic is fewer.

The Mid-Atlantic Ridge is due probably to mountain building activity and the Pacific deeps (average depth 12,000 feet) are of recent origin as evidenced by frequent earthquakes.

(3) *The Indian Ocean*—This is enclosed on its three sides by continental masses. The floor of this ocean is also bordered by narrow deeps. There are coral islands in the

Indian Ocean but fewer than those in the Pacific Ocean.

Classification of the Seas :

Three distinct classes of seas have been recognised. They are :—

(1) *Epeiric seas*—The word *epeiric* has come from the Greek word *epeiros* meaning a continent. Epeiric seas are those which are nearly surrounded by land masses, for example the Baltic Sea.

(2) *Marginal or shelf seas*—These seas are on the continental shelf with open connections with the oceans, for example—the Yellow Sea of China.

(3) *Relic seas*—These were formerly parts of oceans, now cut off by the uplift of land masses, for example—the Caspian Sea.

Composition of Sea Water :

Sea water contains on an average 3·5 p.c. of salt, which consists mainly of NaCl (nearly 80 p.c.) besides some amount of $MgCl_2$, $MgSO_4$, $CaSO_4$, K_2SO_4, $CaCO_3$ etc.

Among other minor constituents are compounds of F, B, As, I, P, Si, Cu, Fe, Pb, Ag, Au, etc. Besides there are also O_2, CO_2 & N_2 in solution with the sea water. From the geological point of view the important constituents are $CaCO_3$, SiO_2 and the dissolved content of CO_2 and O_2. The source of the mineral substances is the land surface and they are brought by rivers in solution and in suspension. Some of the salt materials are taken up by marine organisms for the building up of their shells and as food materials. The p.c. of NaCl however goes on increasing. Sea water therefore becomes more and more saline each year.

Characteristics of the Ocean Floors—The submarine topography is not quite clear due to the lack of observation. Recently the floors of the oceans have been tried to be surveyed by means of sound waves. Such surveying is called *sonic surveying*. In this method sound waves are sent to the ocean floor from an exploration ship. These waves are reflected and are again received by instruments on board the ship. This gives the depth at that place. The position of the ship is known from marine survey maps. This method of exploring has widened our knowledge of the ocean floor. From this we have come to know that the floors of the oceans are irregular and are marked by rises and deeps. The oceans do not attain their greatest depth at the middle of the floor but near their borders. The floors are generally like the shells of a tortoise.

Depth Zones and their Characteristics— The following zones in oceans have been recognised according to depth.

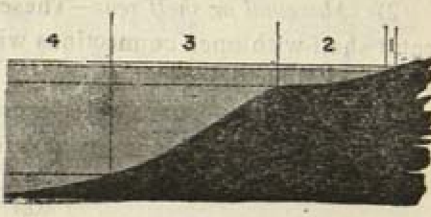


Fig.—24
Depth zones

(1) *Littoral zone*—This includes the area between the levels of the high tide and the low tide. Deposits here are the coarsest and the sorting action of the waves is most conspicuous. Deposits are mostly collected from the continental land masses and are called *terrigenous* (derived from land) deposits. Animals which can live exposed to the air for some time live here. Width is generally 2 miles from the land towards the sea. Total area is about 60,000 square miles. It is also called the *strand*.

(2a) *Neritic zone*—The ward neritic has been derived from the Greek word *neritos* meaning a mussel. This zone includes the area between the tide mark and the continental shelf margin. Total area is nearly 10,000,000 square miles. It is a zone of calmness as well as activity. Wave action and sorting of sediments are conspicuous.

(2 b) *Continental shelf zone*—Depth varies from 350 ft. to 600 ft. and the distance from the land varies from 20 to 200 miles, average 75 miles. Average inclination towards the sea is 10 ft. to a mile. Most of the terrigenous sediments are

deposited here. In the upper part sunlight can penetrate easily and temperature changes with seasons and latitude. Wave action is noticeable, and salinity and turbidity vary also. In the upper part algae and molluscs thrive best. The deposits here vary from gravels or pebbles to finer sediments. This upper part is known as the *Laminarian zone* from the preponderance of the algae Laminaria. In the lower part there is an abruptness in the temperature change. Penetrability of light becomes less and with it aquatic plants also become rare. At the lowest limit finer sediments of mud, lime etc. are deposited. Corals flourish in this zone and coral islands are notable features of this zone. Brachiopods are also abundant.

(3) *Continental slope zone*—The area is nearly twice that of continental shelf zone. Depth is from 600 ft. to 3000 ft. No light can penetrate except in the uppermost part. (Light can penetrate up to a depth of 650 ft. in open oceans). No wind action is felt. Temperature is low and water pressure is very great. The sediments here are very fine. Black, blue and green mud, coral mud, volcanic mud etc. are found here. Deep sea deposits like oozes are also seen in the lower part.

(4) *Abyssal zone*—This includes the zone of deep sea floor. Depth is from 3000 ft. to 12,000 ft. (or more in particular areas).

Investigations of the rocks of the ocean floors and its deposits are carried by means of a device called *bottom sampler* invented by Piggot in 1934. A long (generally 10 ft.) metal tube attached to a gun is lowered from an exploration ship to the sea bottom. On reaching the bottom, the gun fires and the tube is dipped into the floor of the ocean. Then the tube automatically closes and is raised up to the ship. Thus a sample of the deposits and rocks of the ocean floor is brought to light.

With the help of this instrument it has been found that the deep ocean floor is characterised by a slimy, mud-like deposit called *ooze* and *red clay*. The oozes are formed from the remains of minute marine animals and plants. There are many types of oozes named according to the name of the animal or the plant supplying the materials for its formation. These are :—

(a) *Radiolarian ooze*—This type of ooze is formed from the minute shells of Radiolaria (a minutemari ne animal of the phylum Protozoa). The shells are made up of silica. When the animals die, the shells sink to the bottom of the deep sea and collect there. Gradual accumulation of the shells leads to the formation of the ooze. The Radiolarian ooze accumulates at an average depth of of 18,000 ft. and is found generally in the deep and warm parts of the Pacific and the Indian Oceans.

(b) *Foraminiferal ooze* (*Globigerina ooze*)—The foraminifera is another type of marine animals (of the phylum Protozoa). They are minute and their shells are composed of calcium carbonate. When these tiny animals die their shells go on sinking but generally a great portion of these shells go into solution before reaching the sea bottom. The average depth of Globigerina (the chief ooze-forming foraminifer) ooze is 12,000 ft. The Globigerina generally abounds in tropical or temperate open oceans. The Globigerina ooze is the most abundant type of ooze and is specially found in the Atlantic Ocean.

(c) *Pteropod ooze*—The Pteropod or the sea butterflies are floating molluscs (Gasteropods). They thrive well in shallow, warm and open oceans and their shells are composed of calcareous materials generally aragonite. The Pteropod ooze is also characteristic of the Atlantic floor. The accumulation of Pteropod ooze is at a lesser depth than that of the previous one. Pteropod ooze accumulates generally at a depth of 10,000 ft. nearly.

(d) *Diatom ooze*—The diatom is a minute plant and lives in quite shallow water as the penetrability of the sun-light is up to a depth of 650 ft. The shells of diatoms are formed of silica. Diatom oozes are found in high latitudes generally.

Red clay—This is another type of abyssal deposit. It is formed of wind-borne volcanic and land materials, meteoric dust, subterranean volcanic products and iceberg-borne materials. Subordinately manganese oxide, silicate materials and organic remains are also found. The red colour is due to the oxidation of iron materials. Its accumulation occurs at the deepest part of the ocean.

Coral Reefs :—

These are island like structures made up of organic deposits which are abundant in tropical and sub-tropical oceans. In the Pacific Ocean coral reefs are abundant but they are also found in the Indian Ocean. These reefs are structures built around islands, sometimes volcanic peaks, by corals and other lime-secreting minute animals. The corals build protective shells of calcium carbonate around their bodies. When they die, the shells sink and accumulate on the sea bottom. Corals live in swarms in shallow, clear and warm water of the oceans. Millions of millions of these animals die to supply the calcareous material to form the reefs. Coral families build structures in plant-like fashions and the inter-spaces between the branching coralline structures are filled up in due course of time by the deposition of calcium carbonate either by other lime-secreting organisms like the nullipores (algae) or molluscs, or by the debris broken by the sea waves. Gradually an island-like structure is built up which is exposed only at low tides. Coral reefs can not grow above the low tide mark for the minute animals can not stand exposure to the atmosphere for a great length of time.

The formation of coral reefs requires the following conditions.

(1) The water must be warm generally above 68° F (or 20° C). Coral reefs are therefore generally found between 30° N and 30° S latitudes.

(2) The water must be clear. Corals can not thrive in muddy water.

(3) The water must be shallow generally 150 ft. or less.

Types of coral reefs—There are three types of coral reefs.

(i) *Fringing reefs*—These are such as are built close to the main islands or volcanic cones and are laid bare only at low tides. They, so to say, fringe upon the land and are like platforms.

(ii) *Barrier reefs*—These are built away from the mainland like barriers and enclose a body of water between the mainland and themselves. For example the Great Barrier Reef off the east coast of Australia.

(iii) *Atolls*—These are circular reefs enclosing circular lagoons. The Bikni Atoll near the Hawaii Islands, famous for atom bomb experiments, is a famous example.

Origin of Coral Reefs—Corals generally thrive near an island or a volcanic cone where they get some protection against the ocean currents. Reef-building corals gradually construct a platform-like structure near the island or the volcanic cone. In this way a fringing reef is built up. The barrier reefs or the atolls generally point to a depth of formation where no coral can live. As already pointed out corals can only live in shallow water, generally less than 150 ft. deep. But barrier reefs and atolls, rise from more than 150 ft. of depth. Hence their formation can evidently be due to either the submergence of the ocean bottom or the rise of the sea level keeping pace with the reef building.

Subsidence Hypothesis—This hypothesis put forward by Darwin and Dana postulates a submergence of the sea floor. Suppose that a fringing reef has been built about the summit of a volcanic cone and suppose that the volcanic cone is subsiding owing to diastrophic movements of the sea floor. As subsidence of the volcanic cone continues, the corals migrate outwards and upwards. (The growth of coral reef is rather rapid nearly 1 ft. in 10 years). Fringing reef will thus pass on to a barrier reef enclosing a body of water between the reef and the island. Ultimately when the volcanic island will disappear totally, the barrier reef will be converted into an atoll with a circular lagoon inside.

This idea nicely explains the phenomena associated with coral reefs, and submergence of the sea floor is a possibility and actually occurred in geological history. One of the defects of this idea however is that it fails to explain the flatness of the lagoon floors inside the barrier reefs and atolls.

Glacial Control Hypothesis—The other possibility, namely the rise of the sea level has been suggested by Daly. He says that the sea level is rising following the melting of Pleistocene glacial cover. Daly notices that the reefs are steep walled. They are built on submarine platforms which he thinks to be the platforms of marine erosion from pre-glacial islands or volcanoes. The reefs are narrow and hence young, which according to Daly, is due to their post-glacial origin. The defect of this idea however is that it can not explain the growth of coral reefs for more than 325 ft. which is the estimated rise of sea level following the Pleistocene deglaciation.

Borings at different coral islands in the Pacific Ocean have not yet yielded any conclusive evidence in favour of any one of these two above-mentioned ideas. None of them alone is able to explain all the features of coral reef-building but they together combine to explain all these.

Solution Hypothesis—It was proposed by Murray and Agassiz. This explains the formation of barrier reefs as a result of solution of the inner parts of the initial fringing reefs. The corals grow outwards and sea-wards as food materials are abundant there. As a result of this outward and sea-ward growth, the fringing reefs grow wider, but the solution of calcareous material from the inner side removes the connection between the reef and the main island around which the reef grows. The fringing reef thus becomes a barrier reef with a body of water inside. The atolls have grown in a similar way around a submarine platform formed by marine denudation. This idea is unacceptable on account of the fact that the enclosing body of water is saturated with calcareous material, and hence any more solution of calcareous material is not possible by this water.

Marine Destruction, Transport and Construction :--

(A) *Destruction*—The destruction of the sea shore is mainly effected by sea waves and currents though it is largely aided by tides. Wave action is only perceptible to a maximum depth of 700 ft. The depth factor is important in marine erosion. The waves generated by wind are dashing against the shore constantly and bit by bit the shore is eroded. This attack by sea waves is seen everywhere on the coastal region but it depends upon the following factors :—

(i) *Nature of the coast*—If the coast be precipitous, then the wave action is violent. Unobstructed the sea waves dash against the shore directly and a great amount of coastal rock is eroded by such impacts. In a shallow sea over a low-lying coastal plain the wave movement is much obstructed before it reaches the shore. Hence the wave action is less violent in such coastal areas.

(ii) *Nature of the coastal rock*—Naturally if the rock be hard then it is eroded with less rapidity and if it be soft comparatively then it is eroded with more rapidity. Igneous and harder metamorphic rocks have thus chances of surviving to a greater date than the sedimentary rocks. Then the nature of the individual mineral is also to be taken into account. Rocks consisting of soluble materials are eroded easily. In the case of sedimentary and some banded metamorphic rocks, the stratification and banding is an important factor, that is, whether it is inclined, horizontal or vertical and if inclined, whether it is towards the sea or away from the sea. Other factors remaining equal, horizontal beds are eroded away more easily than the vertical beds and in the case of inclined beds those which dip away from the sea are eroded more easily.

(iii) *Presence of joints and fissures in the rocks*—The presence of joints and fissures greatly facilitates the erosive action of sea waves. When the sea waves dash against the jointed rocks the air inside the joints and fissures is highly compressed due to the sudden blow of the waves. As a result the inside air exerts pressure in all directions and acts like a wedge. This highly accelerates the erosive action of the waves. This also facilitates the solution of materials by allowing sea water to percolate into the rock.

(iv) *Presence of rock particles with the waves*—When the sea waves, armed with hard rock fragments, dash against the coastal rocks, a great deal of abrasion is done. These fragments of rocks are thrown against the shore wearing much of the coastal regions. In this process of dashing, the particles themselves are also worn down no doubt.

(v) *Chemical action of sea water*—Sea water ordinarily can take into solution many substances of the coastal regions. The water becomes a much better solvent when it contains some dissolved materials in solution.

(vi) *Wave strength*—The more the strength of the sea waves, the more is the marine erosion.

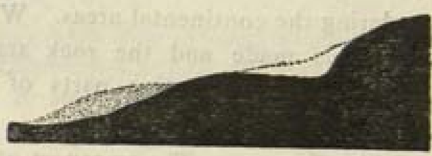
Since the formation of continents and oceans, the above factors are operating and the result is the gradual retreat of the coasts and the development of irregular coast lines bordering the continental areas. Where the rock is hard, less erosion is made and the rock stands projecting into the oceans. Such projecting parts of land are called *head lands or promontories.*

(B) *Transport*—The transport of the products of erosion is also effected by ocean waves and currents. These products of erosion are carried in two ways—(i) in suspension by drifting and (ii) in solution.

Suspended particles as well as those on the bottom of the shore zone are carried further off by means of sea waves. After the breaking up of the coastal rocks the waves try to carry them towards the sea. They are lifted and are carried offshore. The long shore currents try to arrange the sediments parallel to the shore. They thus build *spits or bars* across the coastal region enclosing a lagoon (c.f. Lake Chilka or Lake Pulicat). There is a conspicuous sorting action of the sediments by the wave action. The finer particles are carried away and the coarser particles are left on the beach to form *beach* *shingle.* The coarser sediments, in course of time, are ground fine by the abrasion caused by waves and are then carried away. The terrigneous deposits are not found in deep sea bottom. They are only to be found in continental shelf and margins of the continental slopes.

The materials in solution are also carried further off. Sometimes by reacting amongst themselves i.e. other salt solutions, they may be precipitated, but more often minute organisms, animals and plants, extract certain minerals from them to build their protecting shells or tissues. $CaCO_3$ and SiO_2 are thus utilised by marine organisms.

(C) *Construction*—As the waves dash against the shore, it is eroded away and gradually retreats after supplying rock debris to be handled by the sea waves. A cliff or an escarpment is thus formed. This cliff is called the *wave cut cliff* because it is the work of the sea waves. The products of erosion fall immediately below it and form a more or less narrow flat region adjacent to the shore-line. This is the *sea beach.* The debris from here is carried further off. The coarser sediments are left on the beach to form beach shingle. Finer ones are carried away. As the wave cut cliff retreats, another flat region is formed immediately below the beach over which the water is very shallow, generally 10 to 20 ft. deep near the shore but gradually deepening off shore. This platform-like feature which is the effect of destructive action of the sea waves is called the *wave cut bench or the plain of marine denudation.*



Fig—25
Shore profile

The materials that are carried off shore are deposited near the farthest end of this bench and gradually at its sea-ward margin another more or less flat region (though sloping away from the shore) is built up. This platform-like feature which is the effect of the constructive action of sea waves is called the *wave built terrace.*

The profile from the wave built terrace to the wave cut cliff i.e. a transverse section across a shore is called a *shore profile.* This profile changes gradually. The retreat of the wave cut cliff gives more materials to handle and the wave cut bench widens and the deposition of the materials at the margin of it makes the wave built terrace wider also. Thus the sea waves have two functions to perform, to erode the coastal region and to transport the debris further off. If at any time the waves perform more erosion, more products of erosion will be there to be handled. Consequently immediately after the erosion, more of the energy of the sea waves will be spent in moving the rock materials and less in erosion. Thus there is a balance between marine destruction on the one hand and construction on the other. If the shore region is steep, it is exposed to the full vehemence of the sea waves and consequently the cliff retreats and the region becomes flat. If the region, on the other hand be flat there will be deposition of the beach material near the shore and consequently the shore region will become steep. Thus an equilibrium is maintained at a late stage of marine destruction and construction. When this balancing stage is reached, the shore profile is called a *profile of equilibrium.*

Shore features caused by marine erosion—Due to under-cutting by the sea waves and presence of joints in weak coastal rocks marine erosion sometimes produces a cave-like feature at the base of the wave-cut cliff which is called a *sea cave.* Sometimes such caves proceed landward to a considerable extent producing a *sea tunnel.* The under-cutting and compression of air by the impact of the sea waves cause the blowing of a part of the roof of a sea cave. Sea water, then cutting the caves, spray out from such holes. Such holes on the roof of the sea caves are called *blow holes* or *gloups* and sea caves having such holes are called *spouting holes.* Sometimes two sea caves from two sides of a narrow promontory join by under-cutting it and they produce a gate-way like feature called a *sea arch.* When the roof of a sea cave collapses, an inlet of the sea is caused. When the roof of a sea arch collapses the far off pillar stands in the sea. This pillar-like structure standing in the sea is called a *stack.* Stacks are also caused by marine erosion in vertically jointed rocks. When the coastal rock is weaker, erosion is very pronounced and a small inlet of the sea is made which is called a *core* or a *bay.*

Other features of marine erosion are the wave cut cliff, wave cut bench etc. which have been already described.

Shore features produced by marine construction—Sometimes long-shore currents produce ridges from the products of marine denudation by the dumping up of the rock fragments torn off from the wave cut cliff or brought by rivers. By gradual addition of rock fragments the ridges grow across the shore and ultimately rise above the sea level. If the ridge be straight and if it communicates freely with the ocean water at its far end, it is called a *spit.* If the ridge be curved it is called a *hook.* If the far end of the ridge is not free and there is no free communication with the sea, the ridge is called a *bar.* Bars either generally start from one promontory to another or connect near islands to the main-land.

Classification of the Shore Lines :—

Generally there are two types of the shore lines—one is the shore line of emergence and the other is the shore line of subsidence. Sometimes a complex type is also seen which is a combination of the two.

(i) *Shore line of emergence*—Uplift of the sea bottom or a gradual fall of the sea level is the cause of such coast lines. Uplift of the sea bottom may be caused by the vertical move-ments of diastrophism. Such shore lines newly emerged from beneath the sea, will show raised beaches, (PL—18) wave-cut benches or wave-built terraces. Water is quite shallow near such shores. In the intial stage of evolution of an emerged shoreline, the waves drag the sediments over the shallow bottom and deposit them at some distance from the shore forming off-shore bars and converting the sheltered water back of them into lagoons. Gradually the lagoons tend to be filled up by sediments from the main-land. The destructive action of the sea waves is then confined to the sea-ward side of bars. As a result of erosion the bars get narrower and move land-ward. Ultimately the bars are totally eroded and the shore is exposed to the destruction by sea waves. Shore lines of emergence are at present rare. Deglaciated parts of Finland and Norway show this type of shore line at places.

(ii) *Shore line of submergence*—This type of shore line is very irregular with bays and head lands. Fiords, which are drowned glaciated valleys, are conspicuous features of such shores in glaciated areas. Projections of hard rocks and submerged forests near the coasts are also at times seen. The intial stage in the erosion starts on the head lands and island-like projections. Gradually sea caves, blow holes sea arches, stacks etc. are formed in succession and finally the roof collapses and a narrow inlet is formed. Then bit by bit head-lands are eroded away, so also the islands. The products of erosion are carried away and deposited at some distance to form wave built terraces. Long shore currents also build spits, hooks and bars. Finally these are also eroded away and the shore profile is then converted into a profile of equilibrium. Shoreline of submergence is a commoner feature.

Complexities arise in shorelines due to a combination of the above two types. Some also point to no alteration of the sea-level at all.

Protection of the Coastal Region against Marine Erosion :—

This is an important problem to the engineering geologists. The protective measures to be adopted depend on the study of the wave action at a particular place. One of the effective methods to check coastal erosion is to construct barriers, known as *groynes*, across (transverse) the sea shore. This prevents the carrying away of beach material and thus new surfaces of the coast are not left exposed to wave action. Long shore currents carrying sediments are also obstructed and then they deposit the material to widen the beaches. One of the difficulties with groynes is that though they check erosion at a place they accelerate erosion at another place. Sometimes walls are constructed parallel to the shore. The waves dash against the walls and their velocity is checked. The walls are however liable to be under-cut. Sand heaps are sometimes very effective in checking the impact of the sea-waves.

Coast Line of India :—

The coast line of India is more or less regular with a very few inlets and headlands. The apathy of the Indians to sea-going is in a measure attributable to such unindented coast-line.

The western coast is called the *Konkan Coast* in the northern part from Goa to the Gulf of Cambay and the southern part is called the *Malabar Coast*. On the Malabar coast there are several lagoons. In Kerala they are called *kayals*. This narrow coastal tract supports a good plantation owing to the heavy rain-fall due to the south-west monsoon. The Malabar Coast has a shallow submerged plain—a wave-cut bench or a plain of marine denudation. The narrow bench abruptly deepens. The Malabar Coast seems to be a faulted region.

The north-western coast is called the *Mekran Coast*. This reveals some parallel ridges separated by valleys. This coast also seems to be a faulted area. This is in West Pakistan.

The western coast as a whole is rocky and deep sea water lies close to the shore. Karachi (Pakistan), Bombay, Goa, Cochin are good harbours on this side.

The eastern coast has a wider coastal plain. It is called the *Karnatic Plain*. The water near the shore is shallow. The southern part of the east coast is known as the *Coromandel Coast* while the northern part from the river Kistna is called the *Golkonda Coast*. Madras and Vizgapatam are two harbours on this coast while Calcutta is an inland harbour on the mouth of the river Hooghly. The eastern coast of the Bay of Bengal seems to be submerged, perhaps due to faulting. There is a long north-south running ridge called the *Andaman Ridge* passing through the Andaman Islands, and continuing into the Arakan Yomas after submergence into the bay. The volcanic Narcondam and Barren Islands are separated from this Andaman Ridge by a valley-like depression. There are two more ridges parallel to the Andaman Ridge and west of it. The second is the *Carpenter's Ridge*, and the depression between them is called the *Investigator Deep*.

Permanency of Oceans and Continents :—

Formerly it was believed that continental blocks and ocean basins are unstable in the sense that they have frequently inter-changed their postitions. Closer examination has revealed-that neither deep ocean floors have formed land masses, nor the continental blocks have formed deep sea basins at any time of the earth's history particularly after the Archaeozic time although marginal parts of the continents have been inundated by oceanic transgressions, and shallow parts of the continental shelves of the oceans have formed land masses at intervals. The evidences in favour of this idea are :—

(i) Sonic surveying has nowhere revealed any submerged continental block at deep oceanic depth.

(ii) Deep sea oozes have nowhere been found on the surface of the continents to form sedimentary rocks with exception of certain deposits in some oceanic islands like Barbados, Borneo etc. The sedimentary rocks like sandstone, mudstone and limestone are formed on the shallow continental shelf of the oceans. The included fossils also reveal shallow water organisms. These rocks are seldom to be found on distant oceanic islands.

(iii) Sinking of light sialic continental blocks in heavy oceanic simatic layer is rather a physical impossibility. Small areas may however sink down but sinking of vast continental sectors seems to be absurd. Similar is the case with the emergence of deep ocean floors.

One thing is to be remembered in this connection that this idea of permanency of oceans and continents does not go against the idea of continental drift, for the former idea deals with the vertical movements of the continental areas and oceans while the later deals with the horizontal sliding only.

Marine Transgression—Continental borders have been periodically submerged by the invasions of the seas, thus converting these marginal areas into epicontinental seas. Such temporary invasions by seas are called marine transgressions. The immediate cause of this is either the decrease in the capacity of the ocean, as a result of which some water will evidently spill over, or increase in the volume of sea water. The ultimate causes are the following :—

(i) Melting of ice sheets—This process releases a huge quantity of water which increases the volume of ocean water and thus permits a rise of sea level.

(ii) Elevation of sea bottom.

(iii) Sinking of the continental masses.

The second and third processes are due to diastrophic movements. The idea of Thermal Cycle put forward by Joly explains such changes. The deposits formed by transgressions on submerged continental border areas present some peculiarities. These deposits are called coastal system of deposits. The Upper Jurassic rocks of Cutch and the Upper Cretaceous rocks of Trichinopoly are such deposits. These areas of India were transgressed by oceans during the periods mentioned.

Sometimes after each marine transgression the invaded water recedes and this phenomenon is called *marine regression*, the causes of which are just the opposite to those of marine transgression.

CHAPTER VIII

UNDERGROUND WATER

The water that is obtained from atmospheric precipitation is called *meteoric water*. Water may also be of magmatic origin. This magmatic water is also called *plutonic water* because of its deep-seated origin. Though this magmatic water rises through the minute capillary pore spaces to the surface, its percentage is quite small compared to the water derived from the atmosphere. The water that is entrapped in sedimentary rocks during their formation is called *connate water*.

The water that falls upon the surface is divided into three parts. One part is quickly evaporated, another flows over the surface of the earth and the third sinks below. The part which flows over the surface as stream water is called the *immediate run off*. The part that sinks down is known as the *subsurface* or *underground water*. A part of this underground water again comes out upon the surface through springs, wells (artesian or tube or ordinary) etc. This constitutes the *delayed run off*. A considerable part of the underground water reaches the sea through underground circulation.

The relative proportion of these three parts depends upon (i) climate, (ii) topography and (iii) rock character of a region.

(i) *Climate*—If the climate be humid, evaporation will be slow and the water will flow as run off or underground water. In such a climate the run off may come up to 50 p.c. of the total precipitation. In arid climates, evaporation predominates and run off and ground-water decrease in amount. As the precipitation is small in such areas, run off is very little, nearly 20 p.c. of the total. On an average nearly 30 p.c. may form run off.

(ii) *Topography*—In a steeply inclined surface run off will be greater than other processes whereas on a plain area or more conspicuously in a depressed area underground circulation of water will predominate.

(iii) *Character of the rock*—This factor also derermines to a large extent the relative proportion of three parts. The most influencing factors in this respect are—(a) porosity and (b) permeability.

(a) *Porosity*—It is the amount of open space in a rock body. Hard and compact rocks like the igneous varieties, and metamorphic rocks like quartzites etc. have very little open space in them. Consequently on an igneous area run off will be greater than on a sedimentary area. It is to be remembered that fissures and joints will also come under the open space while determining the porosity of a rock.

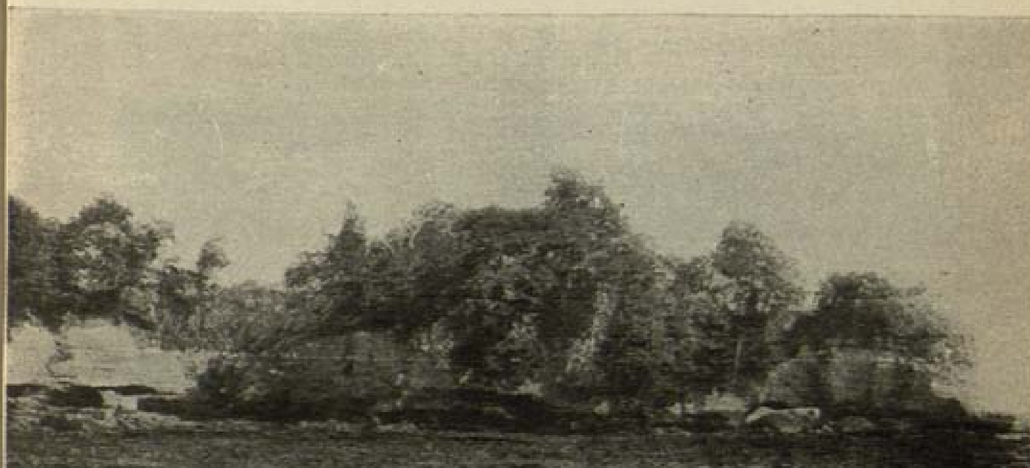
(b) *Permeability*—It is the property by virtue of which water or any solution can pass through the rock possessing this property. Rocks possessing this property of allowing the passage of water or solutions are called permeable rocks, such as sandstones. Those which do not possess this property are called impermeable rocks such as shales. Over a country of permeable rocks therefore, run off will be little in comparison to the underground water circulation, whereas over a country of impermeable rocks run off will be greater in comparison to the underground soaking.

Effect of vegetation on run off—Vegetation exercises a strong influence on the surface run off. It has been found that forest areas have greater rainfall than the areas devoid of forests. Forests produce a cooling atmosphere and vegetation can retain a considerable proportion of moisture. Other factors remaining equal, the amount of percolation will be less and hence run off will be greater in such forest covered areas, than in bare areas.

Apart from evaporation, run off and percolation, a part of the atmospheric precipitation is held by the vegetation and another part by the minerals and rocks in the process of weathering. Ordinarily this part will be negligible but at times the absorbed water becomes considerable.

Pl.—16
Hundru Falls

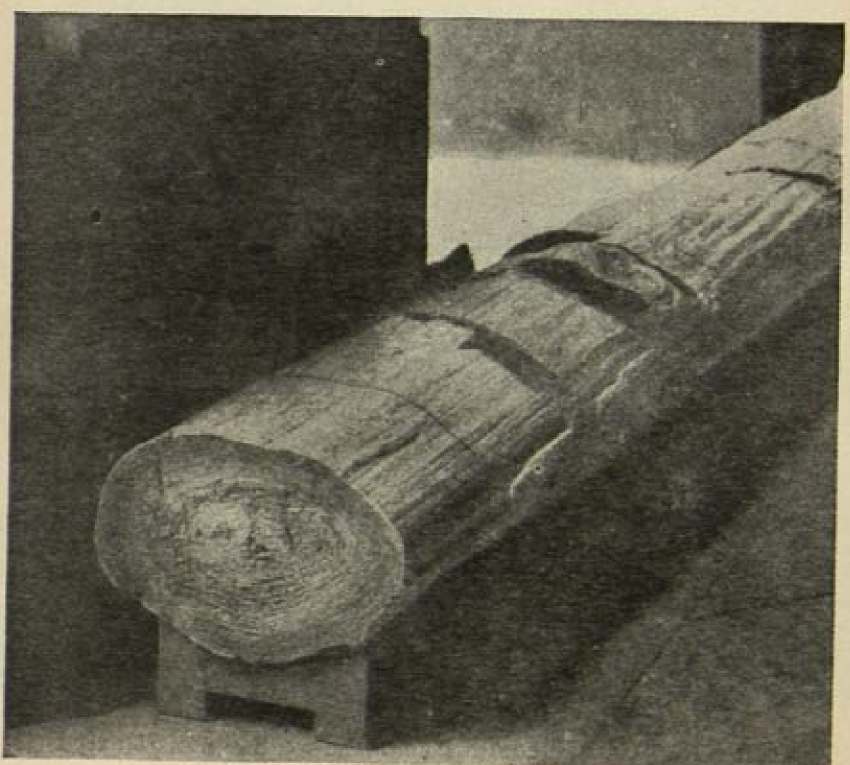
Pl.—17
Jonha Falls



Pl.—18 A raised coral beach of the south end of Henry Lawrence Island, Ritchie's Archipelago

(By courtesy, Director, G.S.I.)

Pl.—19 Calcareous growths in Htamsang Cave *(By courtesy, Director, G.S.I.)*



Pl.—20 Petrified tree, Kumarpur Railway Cutting *(By courtesy, Director (G.S.I.)*

Determination of (a) run off (b) evaporation (c) percolation :—

(a) *Run off*—It is determined by the discharge of all the rivers of an area.

(b) *Evaporation*—It is determined with the help of *Evaporation gauges.* These are tanks with a generally square yard of area and are left floating on large bodies of water. From the evaporation of water from the water surface of such tanks, evaporation at a place can be determined. The average annual evaporation in India is 60 inches.

(c) *Percolation*—It is measured by *Dalton gauges.* These are columns of ground-rock usually one square yard in area which are surrounded by water tight walls, both on the sides and on the bottom. Ths amount of percolated water flows to a measuring vessel and thus the percolation is determined.

Water Table and Zones of Aeration and Saturation :—

At a certain depth below the surface all the rocks are saturated with water which means that all the rock spaces are completely filled up with water. The upper surface of this saturated area is called *water table.* The water table, which is not a flat surface, follows roughly the topography of an area and is more or less parallel to it. Its form and depth are determined by rainfall and topography. The water below the water table is called the *zone of saturation.* The water between the surface of the earth and the water table is called *vadose water* and this zone is called the *zone of aeration.*

Fig—26

Water table and zones of aeration and saturation

Zone of aeration—The thickness of this zone varies with the depth of the water table. Below mountains it is quite deep and below low-lying areas it is quite shallow. Some times it may cut the ground surface near a very low-lying tract. Seepages, marshes and springs are common at such intersection places of the water table and ground level. Hence where the water table will be at a great depth, the zone of aeration will be thick, and when the water table will be at a shallow depth, the zone of aeration will be thin. In a zone of aeration two sub-zones are clearly recognisable. They are :—

(i) *The soil water zone*—Here the water is held by the soil and plants take water from this zone. Clayey soil has got great water retaining capacity while a sandy soil has got very little of it.

(ii) *The capillary fringe*—This sub-zone derives its water from the ground by means of capillary action and lies exactly above the water table. If the inter-spaces in a rock be minute, this zone will have a greater width as in shale whereas in sandstone, this zone is negligible.

Zone of saturation—This zone extends from the water table downwards to the place where all the open spaces in the rocks are completely filled with water. As the open spaces become negligible with the depth in the crust, the lowest limit of this zone is not far below the surface. Leaving the portion of connate and magmatic water, ground water generally becomes rare at a depth of 2000 ft. or 3000 ft. below the surface, although at some places water-bearing rocks have been found at a depth ot 6000 ft. below the surface of the earth.

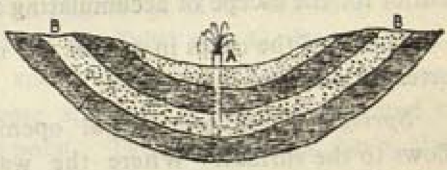
Perched or raised water table—In regions above the water table a lens-shaped body of rock with an upper concave surface may hold a body of water and may thus have a local water table. This water table is called the *perched or raised water table.*

Underground circulation—In the zone of aeration water flows mainly downward. The percolation is chiefly controlled by the forces of gravity, adhesion and capillarity. Gravity causes a downward flow of water. The movement of water always meets with some resistance from the friction of the rock surfaces. In previous beds like those of sand and gravel, the movement is rapid while in beds like those of shales the flow is practically at a stand still. The molecular forces of adhesion tend to retain the water in the interspaces of rock. By the capillary action some water is sucked up through the minute spaces of the rocks underground.

Wells—Supply of water can be obtained from the wells which are dug sufficiently deep to reach below the water table. In regions, where there is great fluctuation of water table due to summer and rainy seasons the depth of the wells should be made very deep, otherwise in the drier months of the year the wells will be dried up. Sedimentary rocks can yield water very easily whereas in igneous and metamorphic rocks, water prospecting is a difficult task. Successful exploration of joint planes, cracks, fissures and planes of schistosity or gneissosity may produce good sites for water supply. In this task the weathered rocks are more promising than the undecomposed rocks.

Aquifer—This means a water producing mass of rock.

Artesian wells—These are a special type of wells operating under special conditions. The name is because of the fact that the first of its kind was made in Artois in France in the 12th century A D.



Fig—27
Artesian wells

Suppose there is a permeable layer like that of sandstone overlain and underlain by impermeable layers like those of shale and suppose they are all in the form of a basin as in the above figure. Now at the outcrop of the sandstone layer water enters into it but it can not go out because of the presence of two impermeable layers on both sides of the sandstone. Water will therefore collect in the curved layer of sandstone. With gradual accumulation of water in this sandstone layer a sort of hydrostatic pressure will develop in the water of the sandstone. If now a bore be made through the impermeable layer to reach the permeable layer, water will at once flow up depending upon the well known hydrostatic principle that water finds its own level. Such a well is called an artesian well. It should be noticed that if the foot of the well on the surface (A) be lower than the outcrop of the sandstone (B), water will flow out on the surface automatically but if the foot of the well be at a higher level than the outcrop of the sandstone, water will rise up to a certain height in the bore but will not reach to the surface and has got to be pumped out. The outcrop of the sandstone, which is the aquifer here, is called the *intake or the catchment* and height of the column of water extending up from the upper surface of the water where the hole is made is called the *head.* A certain amount of loss of head is generally the case because of the friction to the flow of water in the aquifer and the hole. The requisite conditions for the formation of an artesion well are therefore—(i) presence of a permeable layer in the form of a basin overlain and underlain by impermeable layers (ii) sufficient water supply in the aquifer, (iii) absence of outlet for the escape of accumulating water.

Many of the oases in deserts are due to the pouring out of artesian water on the surface.

Springs—These are natural openings through which water flows to the surface. Where the water table is cut by the ground level, springs and more commonly seepages occur (see Fig—26).

Springs are also possible at the outcrop of an inclined pervious bed such as sandstone underlain by an impervious layer such as shale.

Fig—28
Spring

Springs are very abundant in mountainous regions where a valley cuts the water table as in figure—26.

These are the common hillside springs. From such springs sometimes a river may originate and the spring recedes by means of undermining.

Spring water contians some dissolved matter which is precipitated at the mouth of the spring. The more common dissolved substances are the bi-carbonates, chlorides and sulphates of Ca and Mg, NaCl, borax etc. Some gases like CO_2 and H_2S are also present. Some radium salts, Fe_2O_3, aluminium salts, potassium salts are also at times present. These dissolved impurities impart to the spring water some specific characters. The soluble bi-carbonates, chlorides and sulphates of Ca and Mg make the water hard and render it unfit for washing purpose and boiler feeding. The radium and other salts at times impart to the spring water some medicinal properties and such water is used as a remedy for skin diseases, gout, rheumatism etc. In Europe several such springs have been developed into so many spas. Though there is no regular and well-developed spa industry in India, certain springs are places of pilgrimage as for example Badrinath in Garhwal, Jumnotri in Tehri near Garhwal, Rajghir and Sitakund in Bihar and Vakreshwar in Birbhum district of West Bengal. In some springs the water is hot and at times reaches the boiling point. The hot springs have also been described in the chapter on volcanoes and volcanism (Chapter—XIV).

Presence of bromide and iodide salts in the water of Jwalamukhi in Kangra in the Punjab (I) and sulphur in the water of Vakreshwar in West Bengal and Thana springs of Bombay has been reported. The water of Manikarna in Kulu in the Punjab (I) is so hot that pilgrims even boil rice in it. The water of some of the springs of Panchmahals of Bombay is radioactive. The water of Dudkund near Bhuvaneshwar is white because of the presence of kaolin in it.

Indian springs – According to Dr. P. K. Ghose there are four major tracts along which the majority of Indian springs occur. They are :—

(i) *Bihar belt*—including a series parallel to the boundary of the coal fields area, and springs of Rajghir area and Monghyr district.

(ii) *West coast belt*—including Ratnagiri, Thana, Colaba and Surat areas of Bombay.

(iii) *Sind—Baluchistan (Pakistan) belt.*

(iv) *The Himalayan belt.*

There are two other minor belts—one in the Mahanadi valley of Orissa and the other in Chitagong district of East Bengal (Pakistan). Besides them there are some irregular occurrences in Birbhum and Darjeeling districts of West Bengal, in Sikkim and in parts of South India.

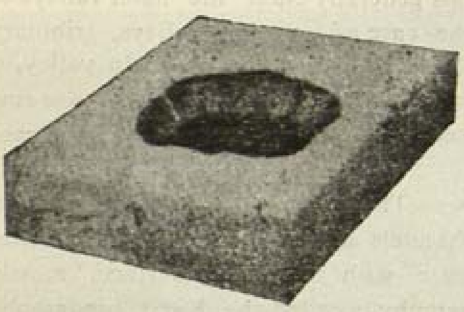
Geological Work of Underground Water :—

Erosion—Due to slow movement of underground water mechanical erosion is practically impossible. Indirectly it can do some erosion by producing land slides. When the soil in highly inclined surfaces becomes saturated with water, the water acts as a lubricating substance thus facilitating the flow of overlying rock mass. The result is the phenomenon of rock-slide which is disastrous in mountainous regions. The brought down rock mass is deposited at the foot-hill region and the deposit formed is called *talus or scree* deposits. Such a kind of flow of soil saturated with water is called *solifluction*. Some amount of mechanical abrasion is possible by underground stream flowing in underground channels.

Solution—Though mechanical erosion is negligible chemical erosion by underground water is highly important and compensates to a large extent the deficiency in mechanical erosion. The solution effect of the underground water is conspicuous in limestone regions or in some other easily soluble rock material such as the rock-salt. Limestone (including dolomite) is ordinarily insoluble in water but if the water contains CO_2 in solution, then it becomes a good solvent for limestone. The chemical process involved is the formation of bicarbonate of calcium which is soluble in water although carbonate calcium is insoluble in water.

The following important structures are formed as a result of underground solution of rocks.

(i) *Sinks*—These are basin-shaped or funnel-shaped hollows, of varying sizes, which are made in limestone regions by the underground solution. Surface water contains a good amount of CO_2 in solution. When this water percolates downward through limestone rocks, a good amount of rock is taken into solution. The result is the formation of a basin with consequent collapsing of the roof into it. As with the formation of Ca-bicarbonate, the dissolved CO_2 is lost, there is more solution near the surface than at depth. Hence naturally these sinks take the form of funnels but other shapes of sinks are also seen whose formation depends upon the structural peculiarities of the rocks. The formation of lakes, in such basins, specially when these basins are below the water table and the outlets are blocked so as not to allow the water to pass away, is possible.



Fig—29
Sink

(ii) *Caverns*—Small caves and underground channels are sometimes formed in limestone regions by the solution of underground rock by sub-surface water, but without the callapsing of the roofs. In these underground caverns and channels streams sometimes flow. The length of these caverns is variable. The Mammoth Cave in Kentucky has a total length of 30 miles underground.

(iii) *Solution valleys*—With continued solution underground rocks are undermined and at last the closely formed sinks and the underground channels are engulfed into a big valley. Such valleys are called solution valleys as their formation is due principally to underground solution. They can be distinguished from a river cut valley by the following facts.

(a) A river cut valley is V-shaped in transverse section i.e. with sloping valley sides, whereas the solution valleys have comparatively steep sides.

(b) The width of river valley is less variable than that of a solution valley.

(c) The river valleys contain water whereas solution valleys if formed above the water table may not contain water unless the outlets are clogged with sediments.

(d) The bed of a river valley is not generally strewn with such a heterogeneous mass of material as is the case with a solution valley.

(e) Tributary streams generally enter the main valleys at the same level but in the case of solution valleys, tributary valleys, if present at all, are hanging above the main valley.

(f) River valleys have no natural bridges whereas some rock remnants may be seen in the form of bridges in the case of solution valleys.

(iv) *Karst topography*—The close formation of sinks, caverns, underground channels and solution valleys produces a peculiar surface feature with a rugged surface, mostly waterless. Such a topography is called the Karst topography in German language. The formation of Karst topography is the result of underground solution of limestone rocks.

(v) *Stylolites*—When water containing CO_2 in solution percolates through the bedding planes of limestone rocks the more soluble parts are dissolved easily and the less soluble or insoluble parts are left as standing columns. Opposite columns, thus produced, interlock producing a zigzag line which is called a stylolite seam.

Transport—The dissolved substances are carried in solution by percolating water until they are deposited. Sometimes they are carried to seas or lakes through underground percolation. At times they are added to the stream water to be carried to seas or lakes. Thus the salinity of lake and sea-water

Pl.—21 Eroded Loess, Khuddera, Jalar Valley *(By courtesy, Director (G.S.I.)*

Pl.—22 Pindari glacier with moraines near Mastoli *(By courtesy, Director (G.S.I.)*

Pl.—23 Eratic blocks resting on Triassic Limestone
(By courtesy, Director, G.S.I.)

increases. Some part of the dissolved substances is also deposited in the interstices of the sediments and acts as binding material. The cementation work is very important in the formation of sedimentry rocks. $CaCO_3$, SiO_2 and Fe_2O_3, form good binding materials. These are often deposited in the rocks, specially calcium carbonate, to form sedimentary rocks. Other types of deposition are discussed below and the deposition from spring water has been discussed in the chapter on volcanoes and volcanism (Chapter—XIV).

Deposition—Apart from the cementation work which is caused by deposition of the dissolved substances in the interspaces of the particles of sediments, the deposition of these dissolved substances produces other distinct structures and features. The deposition depends on the following factors.

(a) *Loss of* CO_2 *and other dissolved gases*—It has been stated that the presence of CO_2 and other gases increases the dissolving power of water. When these are lost as a result of heating, evaporation or reaction, the dissolving power decreases and ultimately some amount of the dissolved substances will be thrown out of solution.

(b) *Evaporation of water*—As a result of the increase of heat or by atmospheric evaporation and consequent loss of some amount of water the concentration of the solution goes on increasing until a concentrated solution is formed. With more concentration, some amount of the dissolved substances is thrown out of solution and deposition of them takes place.

(c) *Decrease of temperature*—With the exception of a few substances which dissolve with the evolution of heat, increase of temperature increases the solubility of a substance and with the decrease of temperature solubility falls. When, therefore, the temperature of the solution falls as a result of loss of heat, some amount of the dissolved substances will generally be thrown out of solution.

(d) *Fall of pressure*—With the exception of a few substances which show expansion on solution, increase of pressure generally raises the solubility of substances and conversely decrease of pressure lowers it. Hence with fall of pressure, deposition of the dissolved substances is likely to take place.

(e) *Chemical reaction*—Deposition from percolating solution can take place as a result of the reaction brought about by (i) the mixing of two percolating solutions, (ii) by the action of gases upon solutions and, (iii) by the action of solid bodies upon solutions.

Some Depositional Features :—

(1) *Stalactites and stalagmites*—These are calcareous deposits of peculiar shape and size formed by percolating water containing $CaCO_3$ in solution. When such percolating solution containing $CaCO_3$ comes to the roof of a cave in limestone region, some amount of water and CO_2 are lost due to loss of pressure, fall of temperature and evaporation. The ultimate result will be the deposition of some amount of the dissolved $CaCO_3$ which will be left hanging as pendant-like masses. Such deposits are called *stalactites*.

Some amount of the solution will fall on the floor of the caves and upon it a dome-shaped or conical deposit will be formed. These deposits which are formed on the floor, are called *stalagmites*. With the increase in size of the two types there may be a union of the two and then a columnar deposit will result. These cave deposits are collectively called *dripstones* (PL—19).

(2) *Geode*—Sometimes cavities of rocks are filled up completely or partially by deposition from underground solutions. Generally, silica but rarely calcite, form such filling substances. The silica is deposited mostly in colloidal state and later turns to be agate (a crypto-crystalline form of silica). The deposition of amorphous silica layer by layer produces the characteristic banding, called *liesegang banding*, in agates. If crystals are deposited from solution, they extend towards the centre of the cavity. These crystals generally resemble the teeth of a comb and *comb structure* originates in this way. Such completely or partially filled cavities are called *geodes*.

Replacement—Sometimes percolating water takes into solution certain substances and deposits an equal volume of another material which the water was carrying in solution. Such substitution commonly occurs molecule by molecule so that the original structure of the dissolved substance is kept intact. Only there is effected a change of composing material. In such ways tree trunks are sometimes changed to solid hard masses which are called *petrified wood* (PL—20). Such petrifaction involves the solution (in some cases but not always) of the woody tissues and an equal deposition of siliceous material. The cellulose is thus replaced by silica but as the substitution takes place volume for volume, the woody structure is exactly preserved. More often there is the deposition of foreign matter without the solution of the woody tissues.

Sometimes the shells of fossils are replaced in a similar way. Besides silica, calcium carbonate, iron pyrites, oxide of iron, calcium sulphate, barium sulphate etc., form such replacing substances.

Concretions—The deposition around some solid particles as the nuclei produces concretionary masses. These are nodular in shape and often occur in sedimentary beds or upon the surface.

The Indian *kankar* is a concretionary deposit. It is formed by the deposition of calcium carbonate into nodular masses around some nuclei.

CHAPTER IX

WIND ACTION

Wind has got a pronounced effect on weather and as a result it influences rain and snow-falls which are again the prime factors in the geological work of streams and glaciers. By blowing over the seas, wind generates sea waves and hence is responsible for coastal erosion. These effects can be described as indirect effects of wind action. Apart from these indirect effects, wind also performs several other geological action in the form of erosion, transport and deposition of materials upon the surface of the earth. These can be described as the direct effects of wind action. This direct action is mainly mechanical in nature and is clearly seen in arid deserts and semi-arid regions, where vegetation is sparse, and on bare coastal regions. In humid regions however the effect of wind action is very obscure for there is plenty of vegetation in such regions which covers the surface from wind action. The intersticial moisture also has a binding effect, thus obstructing the wind action.

Geological Action of Wind :—

Wind action can be divided into three parts—(1) erosion (2) transport and (3) deposition.

Wind erosion again consists principally of three processes. (a) *Deflation* which means the blowing away of rock particles by wind force. The word deflation has been derived from the Latin verb *deflare* meaning 'to blow away'. (b) The blown particles strike against upstanding masses and cause erosion by the mechanical wearing of the rocks. This is the *wind abrasion.* (3) The blown particles themselves are also worn round by the impact of other particles. This process is known as *attrition.* They all add to wind formed products.

Deflation—This causes removal of the loose particles. In coastal regions particles of the beach sand are dried during the recession of the sea water at low tides and wind carries the dried particles inland from the coastal regions. It has been calculated by Sir T. H. Holland and Dr. Cristie that nearly 130,000 tons of salt particles are carried annually from the Rann of Cutch region by the south-west monsoon towards Rajasthan.

In all these areas wind action is pronounced only on loose particles or weakly cemented or extremely weathered rocks. When wind blows a huge quantity of fine dust particles is lifted up and this covers the sky creating a suffocating atmosphere. The blowing away of the loose particles from the ground causes depression on the surface and in desert regions such depressions turn to be lakes after heavy showers of rain, though temporarily. There is thus an excavatiug action of wind on the ground. There is however a limit to this deepening by wind. The base level of this process is the water table of the area and when this is reached, blowing away of loose particles altogether stops. It is to be remembered however that with the erosion of the ground, the water table also tends to go down.

Deflation is a formidable menace to cultivable lands. Judicious planting of trees or fencing can alone arrest this destructive process. Factors aiding deflation are the absence of vegetation, absence of moisture in the interspaces of rocks, looseness of the rock particles and the high velocity of wind.

Wind abrasion—This effect is illustrated by artificial sand blast produced on smooth and clear surfaces when these surfaces get frosted appearance. The loose particles that are blown away by wind form good eroding agents. These particles strike against the exposed bed rocks in arid areas. As a result of this abrasion a great deal of erosion is done on them. The bed rocks are spotted, grooved and polished. Wind abrasion depends largely upon the character of the blown rock particles and the bed rock. Ideally the effects will be at their maximum when (i) the blown particles are hard, (ii) the bed is soft and (iii) the velocity of wind is great. Rocks consisting of hard and soft parts get differential abrasion and a honey-comb structure is produced.

One of the conspicuous structures produced by wind abrasion is the formation of pedestal rocks. These are curious features with wide rock caps balancing on narrow columns. These structures are produced by wind abrasion on upstanding rock masses. As the blown particles are not carried higher, lower regions of upstanding rock masses are only abraded and undercut. This makes the foot regions slender while the head regions remain more or less untouched. The ultimate structure is a wide rock cap standing on a slender rock column. Such rock columns are called *pedestal rocks.*

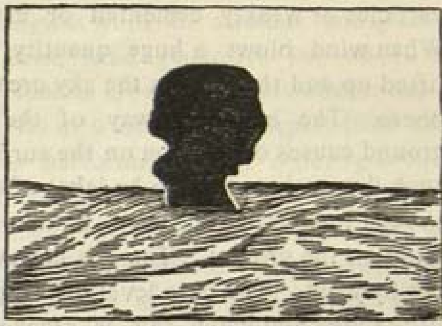


Fig.—30
Pedestal rock

A peculiar product of abrasion is the facetted and angular rock fragments which are called *ventifacts* meaning 'made by wind.' These are also known by the German name *dreikanter.* Wind blowing in a particular direction cuts a slightly curved, more or less flat surface on a rock fragment. When the direction of the wind changes or when the rock fragment rolls to another side then another face is cut by wind abrasion. In this way several smooth faces are developed on the rock fragments which meet at some angles with each other. In this way ventifacts are produced. Ideally ventifacts consist of more or less three equal sides. Harder rock fragments and generally quartz pebbles form ventifacts.

Sometimes wind abraded rock fragments show peculiar black coated polished surfaces. The black substance is manganese oxide which is derived from the interior of the rock.

The natural effects of wind abrasion are also seen in the frosting produced on pane glasses of houses on coastal regions and abrading effects on wooden telegraph posts.

Attrition—The rock particles not only abrade the exposed bed rocks but they themselves are also abraded by colliding against one another. This produces a rounded appearance of the individual fragments. This is because of the fact that the rock particles have chances of getting equal abrasion from all sides while on transit. The greater velocity and the greater length of transit are also contributing factors. Rounded desert sand grains are often called *millet seed sands* because of their resemblance with millet seed grains. Along with others this characteristic of the individual grains of rock particles in a sedimentary rock like sandstone betrays the history of its formation. The roundness produced can easily distinguish a wind-formed sandstone from a river-formed sandstone because in the latter case individual grains will not be perfectly spherical.

Transport—The transport of the loose particles is also effected by the velocity of wind. As the wind action is prominent in desert regions and semi-arid regions devoid of vegetation, there is practically no obstacle to arrest the forward movement of wind excepting by some infrequent rock masses or buildings on coastal regions. When they meet with an obstacle the forward movement of wind is stopped and the load is deposited at the place. Hence these fragments are carried to a great distance. Generally the load is not carried very high.

Deposition—When the forward movement of wind is arrested the sedimentary load is at once deposited. Sometimes this deposition may be a temporary one to be swept away again by the next wind blast but at times they are deposited more or less firmly and get stability for a great length of time. Such wind formed deposits are called *aeolian* deposits after the name of Aeolus, the god of wind. One peculiarity of such aeolian deposits is the sorting action produced upon them as is the case with the water-borne sediments. The rock particles in an aeolian deposit are arranged according to their size and weight. The lighter and finer products are carried farther than the heavier and the larger ones. The finest particles are carried farthest and float for a considerable time in air and then settle anywhere on the continental sectors or oceanic areas.

Loess—It is a special kind of aeolian deposit. This German name has been coined in the geological literature from an Alsatian word meaning fine-grained buff-coloured deposits. Ordinarily loess does not show any horizontal layering but consists of loosely held layers of variable thickness and is traversed by vertical roots of trees giving the deposit a vertical cleavage. This is responsible for the formation of steep scarp-like aspect from such deposits by erosion. This type of deposits is very fertile. Chemically loess consists mostly of clay with microscopic grains of quartz, felspars, mica, calcite etc. Loess also contains, at times the remains of land animals.

Loess is a conspicuous deposit in Northern China. It covers an area of nearly 230,000 square miles there and has thickness of nearly 300 ft. The material has been derived from the Gobi desert and borne by wind. This area is extremely fertile. The yellow colour of the deposits has given the name of the Yellow River and the Yellow Sea of China. Such deposits are easily eroded away as they are very loose (PL—21).

Loess also occurs in Central Europe, U.S.A. and South America. Similar deposits in the Mississippi Valley have been named *adobe*.

Dunes—These are mounds of sand formed by the action of winds. When the surface is irregular, it is called a *sand hill* but when it is in the form of a round hillock or a ridge with a crest it is called a *sand dune*. Sand dunes are prominent features in desert regions and coastal areas. In the coastal areas wind blowing inland produces a belt of sand dunes.

The formation of a sand dune is due to the obstruction to the movement of wind carrying sand particles. This obstruction is generally offered by the irregularities of the surface or by any bush or any building falling on the way of wind. Deposition of the load begins with the slowing down of the velocity of wind which also decreases the transporting power of wind. Once started deposition goes on and as this accumulation grows up, it offers obstruction to the movement of wind. Ultimately there results a round hillock called a sand dune. Such dunes are variable in height, varying from 100 to 300 ft. or more, depending upon the availability of rock particles and the velocity (and hence the transporting power) of wind. Desert regions are conspicuously dotted with such dunes. From one-third to one-fifth of the total area of every desert is covered by dunes.

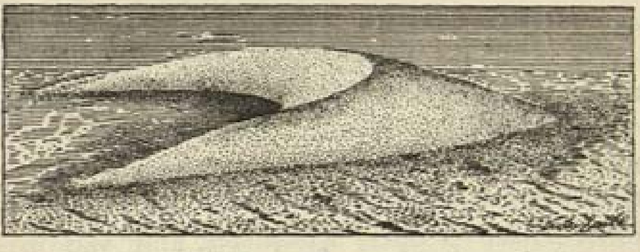
In structure a dune has a gentle slope towards the wind-ward side and a steep side towards the lee side. The lee side is also called a *slip face*. Sand particles are swept on the wind-ward slope. They fall over the crest and come to rest on the lee-ward slope at some angle which is greater than the angle of the wind-ward slope. On the lee-ward side the sand grains rest at an angle which is called the *angle of repose*. This angle varies from 20° to 40° depending upon the coarseness of the particles. The coarser ones will rest at greater angles of repose. The wind-ward slope shows gentle ripple marks. Another feature in the structure of sand dunes is the cross-bedding in the layers. This is produced by the irregular deposition on the eroded surfaces of the dunes, the erosion being caused by subsequent powerful wind gusts.

A dune often moves forward from one place to another in a desert region. This is effected by the lifting of sand grains from the wind-ward slope and adding these on the lee-ward side. The movement is stopped when a shrubby cover firmly binds the sand particles so as not to allow them to be lifted.

Close formation of sand dunes in a region produces an irregular surface. In the depressed areas water often collects specially after heavy showers of rain and forms temporary lakes. In more arid regions however these depressed areas form *oases*.

Two distinct types of dunes are found in desert regions. They are—(a) *barchan* and (b) *longitudinal dune*.

(a) *Barchan* is a crescent-shaped dune with two tapering arms. Their formation is due to the deposition, while moving forward, along the two flanks and consequent prolongation of these flanks into stretched arms. The word barchan has come from a Turkish word.



Fig—1
Barchan

(b) *Longitudinal dunes* are linear accumulations in ridge-like forms of sand particles. These ridges often occur in parallel groups and show toothed summits. These are called *seifs* in the Sahara desert.

CHAPTER X

GLACIERS AND GLACIATION

Glaciers are river-like masses of ice which flow down-hill under the action of gravity.

Avalanches are masses of ice flowing down-hill with great rapidity. As a result of the terrific speed avalanches produce considerable gusts of wind. Avalanches bring materials like rocks, soils etc. from higher to lower levels.

Formation of Glaciers—The distribution of snow is controlled by latitude and altitude. At high latitudes and high altitudes snow is abundant. The lowest line of perpetual snow is called the *snow line*. This in the case of the Himalayan glaciers is 15,000 ft. nearly in the eastern part whereas it is 17,000 to 19,000 ft. in the western part. Except in Australia snow fields or catchment basins of snow are to be found in all parts of the world. The snow when it first falls is in the form of cotton. Successive snow falls press the lower snow and as a result air is squeezed out. The snow after being subjected to considerable pressure assumes a flaky structure. More pressure exercised by successively piled up snow, changes the snow flakes into granular masses under the influence of moisture. These granular masses of ice are called *ne've'* in French and *firn* in German language. Bubbles of air due to the expulsion of air through the melt water and its subsequent refreezing are abundant in ne've'. This ne've' is intermediate in character between snow on the one hand and compact ice on the other. As snow continues to fall and gather, the thickness of the snow field increases and this causes more pressure upon the lower layers of snow. The air in the ne've' is then squeezed out and the ne've' turn to be compact ice. The ne've' is opaque due to the presence of air bubbles though individually the granules of ice are clear. Ice is also clear but layering is a very conspicuous feature in it. The layering may be caused by the successive snow falls or due to the presence of dust particles. Sometimes the clear, compact ice shows blue bands. The snow-field is, at a time, composed of compact ice at the base, ne've' in the middle and unconsolidated snow at the top.

Movement of Glaciers—In mountain slopes such masses of ice, ne've' and snow ultimately begin to flow down-hill under the action of gravity. The movement starts when the weight of the mass becomes more than the retarding friction along the slopes and is also dependent on the temperature. The moving mass of ice is a glacier. *Glacieret* is a term which denotes an intermediate mass of ice between a moving glacier and a non-flowing snow field.

The movement of a glacier is serpentine and conforming to the trends of the valley in which it flows. Ice thus behaves as a viscous mass. There is no wonder in it because though ice is a crystalline solid (hexagonal), it can be made to flow by the application of sufficient force. This force comes from the overlying mass of ne've' and snow. As a rule glacier ice consists of two parts—one moving below which is viscous due to pressure and other upper part which is solidified and is carried by the flowing lower mass. We thus find that cracks or *crevasses*, as they are called, exist in the upper part of glaciers.

The movement is greater in the central part than at the sides. This is due to the fact that the central region experiences friction only from the ground below but on the lateral regions there is friction both from the sides as well as from the base. The terminal deposits thus present a convex form towards the outward and down-hill side.

The lowest limit of glacier movement is dependent on temperature mainly. Glacier retreats or thins out by the melting of snow. Normally the flow of a glacier is maintained by the accumulation of snow in the catchment area. Whatever portion of ice is melted and evaporated is replenished by the supply from the snow field. There are, therefore, two opposing factors in the glacier movement—(i) the supply of snow and consequent pressure from up-hill region and (ii) melting of ice tending to cause shrinkage in the volume of the glacier and its consequent retreat. The snout or the front portion of a glacier moves on below the snow line until the melting and evaporation gain the upper hand and stop the movement. The temperature rise is not the only factor in the forward movement of a glacier. It also depends upon the volume and velocity of a glacier. If the volume be large and the velocity be considerable, wastage can not check the forward movement of a glacier. Generally in the warmer months a glacier shrinks and in moist months it advances. Glaciers near the seas sometimes reach sea water. Parts of it break there and float on the sea water. Such floating ice hills are called *icebergs*. They form danger to navigation. The famous Titanic was wrecked by the collision with an iceberg.

The lowest limit of the Himalayan glaciers is not the same throughout the Himalayan region. In the eastern part, in Sikkim, they descend to as low a level as 13,000 ft. In the western part, in Kashmir, they descend to as much as 8000 ft.

The movement of a glacier varies from a fraction of an inch to more than 100 ft. per day occasionally. In the case of the Himalayan glaciers the movement varies from 1 inch to 3 ft. nearly per day. The daily movement, according to the Italian Expedition in 1909, of the Baltoro glacier in the Karakoram is 5 ft. 10 inches and that of Fedchenko in the Trans-Alai Range of the Pamir Plateau is 1½ ft.

Excepting the occasional temporary advance, most of the glaciers are generally retreating at the present time. They were numerous and advancing in Pleistocene time. The retreat is due mainly to the melting of ice. The product of melting, the melt water, gives rise to englacial and subglacial streams also feeds other rivers. The Himalayan rivers are to a large extent fed by glacial water.

Crevasses—These are cracks of variable breadth and depth on the upper surface of a glacier. These cracks testify to the crystalline and solid nature of the glacier ice, at least on the upper part, and are formed where a glacier bends low over and inclined surface. Where the glacier mass takes motion, a crack is formed running parallel to the rocky wall behind. To this crack the German name *bergschrund* has been given. Crevasses are of several types according to the position at which they are formed.

(1) *Longitudinal crevasses*—These are parallel to the length of the glacier and are formed where a glacier mass emerges from a narrow valley to a wider valley. The availability in space causes the glacier to expand side-ways and longitudinal cracks are formed.

(2) *Transverse crevasses*—These run transverse to the length of the glacier or are parallel to the breadth of the glacier mass. They are caused by slight increase in the inclination of a mountain slope. These crevasses are convex downward owing to greater movement of the central region of the glacier mass.

(3) *Marginal crevasses*—These are cracks formed along the valley sides pointing to up-hill direction. They are also the result of greater movement of the central region of a glacier mass.

Crevasses are likely to be filled up later. They are often covered by dangerous ice bridges which may collapse with slight weight.

Types of Glaciers—Depending upon their structure and location glaciers are classified into three classes—(i) valley glaciers, (ii) piedmont glacier and (iii) ice sheet.

(i) *Valley glaciers*—These are also called *mountain glaciers* or *Alpine glaciers*. Glaciers that flow down a valley like a river are called valley glaciers. They are confined by the valley walls, conform to the valley trends and do not outflank them. They are the commonest type of glaciers. There are about 2000 of them in the Alps. The Hubbard Glacier in Alaska is the longest valley glacier in the world with a length of 80 miles. The Himalayan glaciers are mostly of this type. Indian glaciers are those of the Punjab, Kumaon and Nepal Himalayas such as the Rimo of the Punjab Himalayas (length 25 miles). Gangotri (length 15 miles), Milam (length 10 miles), Kedarnath (length 9 miles) of the Kumaon Himalayas and Zemu (length 16 miles and 650 ft. thick) of the Nepal Himalayas. Most of the Himalayan glaciers are small being of 2 to 4 miles in length. Larger glaciers are however met further north in the Karakoram Range, the noted ones of which are the Biafo (37 miles long) and Baltoro (36 miles long and 400 ft. thick) falling into the Shigar tributary of the Indus, and the Hispar Glacier (38 miles long) and the Batura (36 miles long) flowing between the Hunza Valley and the Siachan (45 miles long) falling into the Nubra tributary of the Indus. The Fedchenko in the Trans-Alai Range of the Pamir region is 48 miles long and 1800 ft. deep. It is however outside the proper Himalayan region.

Glaciers occupying hanging valleys are called hanging glaciers. They are distinct from the main valley glaciers and do not meet the main glaciers at the same level. Some of the Himalayan glaciers are of this type especially those of Sikkim and Kashmir.

(ii) *Piedmont glaciers*—These glaciers are intermediate in form as well as origin between the valley glaciers on the one hand and ice sheet on the other. This is a type of glacier formed at the foot of mountains. When two or more valley glaciers come out of the valley and fall to the plain they unite to form a bigger ice mass which is called a piedmont glacier. Noted examples are Malaspina Glacier and the Bering Glacier in Alaska.

(iii) *Ice sheets*—These are huge covers of ice, enormous in size and thickness, that rise high above the mountain peaks and completely bury them. At present Greenland and Antarctica only present examples of this type. Smaller ice sheets are called ice caps or plateau glaciers and are found in Iceland. Ice sheets generally discharge into the seas their masses of ice as icebergs. Towards the marginal part and near the sea, where the thickness is less, high mountain peaks stand up as islands in oceans. The island-like projections are called *nunataks*.

Geological Work of Glaciers—This consists of three distinct processes of erosion, transport and deposition. Together these processes are included in the term glaciation. Distinct features are associated with each of them which are discussed below.

Erosion—The erosive action of glacier is affected by abrasion and is aided by frost-action. In regions above the snow line frost wedging is an important factor of erosion. The region which encloses a snow field, shows an amphitheatre-like basin and is surrounded by steep-sided blunt headed peaks which are called *cirques or corries.* The area enclosed by cirques gathers snow and nourishes glaciers which move outward and downward. The cirques show extremely rugged topography. They are the result of the process called *nivation*. Nivation consists of quarrying of rocks mostly by frost action. During day time or in summer days, with the rise of temperature, some snow will melt and the melt water will percolate through the joints of the rocks. During night time the water will freeze and with consequent increase in volume, the rocks will experience a shattering effect. As a result of this part of the rocks are quarried and the debris is plucked and carried away by avalanches or by the melt water flowing downward or by glaciers. Nivation is concentrated at the flanks and the under-side of a glacier. The result is the scooping of a hollow. As the process continues the sides of the valleys are undercut and become steeper and irregular. In course of time the peaks turn to by cirques. These cirques recede with progressive erosion and the glacier basin is enlarged thereby. When the glaciers vanish by melting as a result of the rise of temperature, the hollows turn to be lakes. Where two cirques meet at an angle the dividing ridge between them is called an *arete*, and three or more cirques unite and after erosion form turreted masses called *horns.*

Strictly speaking nivation is not a glacial action though it is intimately associated with it. True glacial erosion starts with the movement of glaciers. This consists of mechanical quarrying and abrasion by glaciers, aided, no doubt, by frost.

action. The erosion by glaciers depends upon several factors among which the following are important.

(i) *The thickness of the glacier ice*—It is a very important factor in glacial erosion. The more the thickness, the more the glacial erosion. The thinner parts of glaciers perform less erosion and sometimes pass over the bed rock without doing any erosion.

(ii) *Amount of rock material carried by the glacier* —The products of erosion, particularly of frost action, fall on the glacier mass and are carried away. Sometimes the rock debris reaches the bottom through the crevasses. Rock fragments also are torn away by glaciers from the bed rock by plucking. Glaciers exercise firm grip upon rock fragments. While moving over the bed rock, the rock fragments effectively grind the floor, wearing them constantly. The firmness exercised by glaciers on the stones is a factor in glacial erosion. Where the grip of the glacier is loose, the erosion is not pronounced, as in melting ice, but where the grip is firm abrasion is done effectively. The sides of the valleys also are worn away and the debris is added to the glacial *drift*, which is the entire mass of products carried by glaciers. As a result of the erosion the bed rock is smoothed, polishsd, rounded, striated and grooved. The striae or the linings produced by glacial abrasion are very conspicuous in the valleys occupied by glaciers. These striae points to the direction of flow of the glaciers. If the initial bed rock be hummocky the small hillocks are abraded and low and rounded mounds are formed which are called *roches moutonnees*. These may also result from hard parts of bed rocks while the surroundidg weaker rock mass may be eroded away easily. The

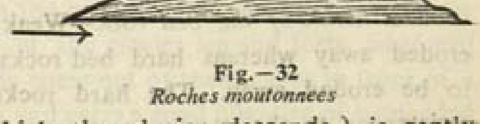


Fig.—32
Roches moutonnees

up-hill side, (from which the glacier descends) is gently sloping and is called the *stoss side* while the down-hill side is steep and is called the *lee side*. Sometimes very hard rocks, like volcanic plugs, offer great resistance to the ice flow and stand as pillars in the glaciated valleys. These structures are called *crags* and the lee side, which is sloping in this case, is called the tail. This structure is just opposite to that of roches moutonnees.

Not only the bed rock is abraded smooth but also the sides of the valleys occupied by glaciers. The valleys occupied by glaciers are U-shaped instead of being V-shaped as in the case with the valleys occupied by rivers. The stream-formed spurs are also eroded away. As glacier ice conforms to the valley trends, length-wise the valleys occupied by glaciers are serpentine.

In the process of abrasion the rock fragments are also worn away. They develop conspicuous facets which are smooth and striated. The finer products of erosion, the rock flour, both from the bed rock and from the abrading fragments are carried away by melt water.

The tributary valleys, in the case of glacier-occupied ones, are not at the same height as the main valleys. This is because of the fact that the glacier ice is thicker in the main valleys than in the tributary valleys. The main valleys are therefore eroded away more rapidly while the tributary valleys are eroded less rapidly. The result is that the tributary valleys are left hanging above the main valleys. After the disappearance of glaciers these hanging valleys form water-falls.

(iii) *The velocity of glaciers*—The greater the velocity of the glaciers, the more is the erosion. Roughly the abrasive power varies as the cube of the velocity of the glacier. Steeply inclined surfaces thus help speedy glaciation. Slowly moving ice sheets are less powerful eroding agents than the fastly moving valley glaciers.

The nature of the bed rock—Weak bed rocks are easily eroded away whereas hard bed rocks take considerable time to be eroded away. The hard rocks on the way offer great resistances to the glacier movement and form crags. On the bed rock itself the effect ts conspicuous. Where the bed rock is weaker, erosion is more pronounced than where the be d rock is hard. This differential erosion at times produces a step-like aspect in the glaciated valleys. This step-like feature is called the *glacial stair way*. They may also result from the quarrying of vertically jointed rocks.

One peculiarity of glacial erosion is that glaciers can erode the valleys below the sea level. The down-cutting by rivers stop at the sea level but glaciers can deepen their valleys below the sea level. This is known as over-deepening by glaciers. In the sea coasts this produces characteristic glaciated deep submerged valleys which are known as *Fjords* (or *Fiords*). Originally the valleys near the coast was eroded below the sea level by over-deepening. Afterwards either by the rise of the sea level or by the sinking of the land mass which may be the effect or isostatic readjustment following Pleistocene deglaciation, the sea water invaded the coast and these valleys formed inlets of seas. They are abundant in high latitudes.

Melting of ice and related features—There are some features which are the direct outcome of melting of glacier snow. They may be considered here though their origin is not wholly due to erosion.

As already pointed out the rise of temperature causes melting and evaporation throughout the entire surface of a glacier. This is specially pronounced in summer days. The product is the melt water. Where the slope is favourable this melt water forms streams and glacier supports them on its upper surface. Where the slope is opposing it forms lakes. Such streams generally fall into the surface fissures (the crevasses) and by the whirling action of stones carried by such rivers, cylindrical hollows are made which are called *moulins* or *glacier mills*. Such hollows sometimes reach the bed rock and leave pot hole marks on the bed rock but generally they merge into the inside caves in the glacier ice and form *subglacial* streams. These streams come out of these caves in front of a glacier from underneath and carry a good quantity of suspended fine rock materials which turn the stream water milky and this water is called *glacial milk*.

Streams occuring in the glacier body itself are known as *englacial streams.* Streams supported on the upper part of a glacier are called *superglacial streams.* These are frequent along the lateral margins of glacier valleys. Streams occuring at or near the bottom of a glacier are called *subglacial streams* The terms subglacial, englacial and superglacial also refer to the rock materials carried by glaciers with the same meaning.

The dust particles on the surface of a glacier are likely to absorb more of solar heat in comparison to surrounding regions of snow. Hence this dusty patch will melt the snow beneath it and small basins will be formed. These basins are called *dust wells.* But if the thickness of the rock fragments be considerable, the reverse will be the case. The rock material will serve as an insulating cap and prevent the snow below from melting. Sometimes huge blocks are seen standing on a pedestal of snow whose origin can be explained by the above process. These blocks are known as *glacier tables.*

Kettles—These are basin-like hollows made in the out-wash plains or other type of glacial deposits. Their diameters range from a few yards to a few miles. Commonly they contain water. These depressions are the result of melting of ice either wholly or partially buried under glacial drift and consequent collapse of the upper part.

Fig—33
Kettle

Transport—All the products of erosion are in a state of progressive transit outward and down-hill by the glacier ice.

A huge quantity of rock debris is carried by glaciers on their upper surface, which is called the glacial drift. This rock debris comes from the valley sides. Avalanches also contribute to the rock debris. By the process of plucking some rock material is picked up from the bed rock. Regelation i.e. melting under pressure and subsequent freezing, is a very important process in this respect. The materials are arranged along the sides, under the glacier and notably at the terminus. All the rock materials tend to accumulate at the terminus. From the terminus melt water in the different types of glacial streams carries the rock material to the seas or lakes. Glaciers themselves, in coastal regions, carry their rock debris to the seas.

Deposition by Glaciers and Associated Features :

One of the peculiarities of glacial deposits is the unassortment of these deposits. In glacial deposits big boulders and finest rock materials are all dumped at a place. In this respect glacial deposits are unlike the river and wind-formed deposits. In the river and wind-formed deposits, the sediments are arranged according to their size and weight, so that the big and heavy blocks occur near their places of origin and the finer sediments are carried further away. Glacial deposits are wanting in this arrangement. The unassorted glacial drift consisting of rock materials ranging in size from boulders to the finest rock flour is known as *till*. The rock formed from till is called *tillite.* When, however, snow melts, glacial streams are formed and then the combined effects of water and ice are noticeable upon the sediments so that they become partly or wholly sorted, washed and stratified. Drift of this nature is called the stratified drift. The facetted and striated stones in them betray their glacial origin.

The big boulders which are carried by glaciers are known as *erratics* (PL—23). They are huge in dimension. Some of these are deposited in unstable elevated positions and are known as *perched blocks* (*roches perchees*). At times they are delicately balanced upon the glaciated bed rock. These are then known as *pocking stones or logging stones.* Their dissimilarity in rock composition with the rocks below points to their transport to the place.

Types of moraines :—

Most conspicuous of the glacial deposits are the different types of *moraines* which have received different names according to the place of formation in glaciated valleys. They are :—

(1) *Ground moraines*—The moraines (or drift) which are deposited upon the ground or the bed rock upon which a glacier is moving are known as ground moraines. In thickness they are thin and their surface is irregular due to uneven deposition of rock materials carried by the glacier because whatever load of rock debris the glacier can not carry, is deposited on the bed rock over which the glacier flows and this results in uneven deposition.

(2) *Lateral moraines*—These are the moraines which are deposited along the margins of the glaciated valleys and are ridge-like accumulations of rock debris which are sometimes 100 ft. or more in height. The lateral moraines often persist for sometimes even after the disappearance of the glacier.

(3) *Medial moraines*—These are also ridge-like accumulations of rock debris formed along the middle part of a glacier. They originate by the union of two lateral moraines of two intersecting valleys. They are transitory in existence and are easily removed away because of their central position.

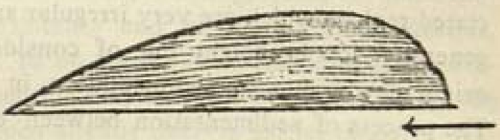
(4) *End moraines or Terminal moraines*—These are accumulations of rock debris at the end of terminus of a glacier. Their height is sometimes 100 ft. nearly but they are of a very small width. Their length is determined by the width of valley floor. They present a convex side downward which is due to faster movement along the central part of a glacier.

There are two more types of moraines, one is the *englacial moraine* and the other is the *subglacial moraine*. They denote only masses in drift but no depositional features.

The rock debris that is enclosed by a glacier mass is called an *englacial moraine*. The dust particles between successive snow falls which make layering conspicuous in the compact ice and the part of rock debris buried on the upper surface of a glacier which falls into the crevasses and sinks below form the englacial moraine.

The moraine that occurs near the sole of a glacier is called the *subglacial moraine*. The part of the rock debris which reaches the bottom through the crevasses and the rock material that is plucked on the way, constitutes the subglacial moraine.

Drumlins—In glaciated regions, the ground moraines consist of low mounds of clay which sometimes, contain cores of bed rock. These small hillocks are of the shape of inverted tea-spoons. Drumlins have their long axes parallel to the direction of ice movement. Their up-hill sides are blunt and the down-hill sides are smooth and gently sloping. They thus show features which are just opposite to those of roches moutonnees. They are sometimes one mile or more in length and nearly 200 ft. in height.



Fig—34
Drumlin

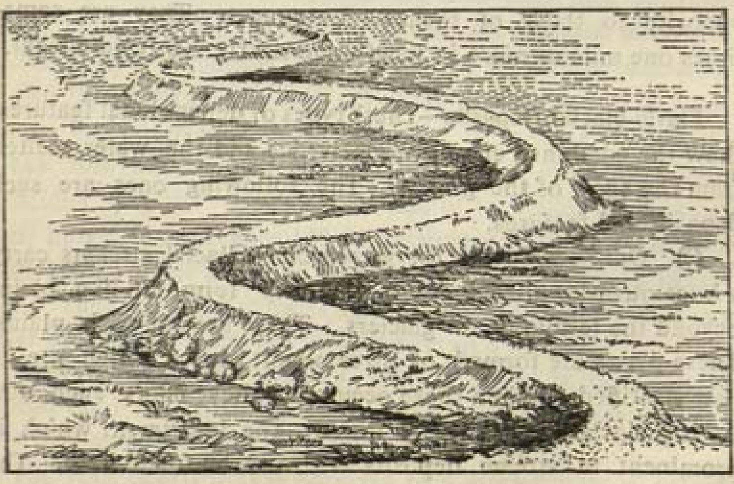
Fluvio-glacial Deposits—These types of depositional features show the combined effects of glacier ice and the water melted from the snow of the glacier. The following ones are such depositional features.

(i) *Outwash plain or overwash plain*—Glacial streams carry a huge quantity of rock debris and they form fan-like plains beyond the terminus of glaciers. These are out-wash plains. These plains are formed of stream-built drifts which are in part stratified. When these occur on valley floors such out-wash plains are called *valley trains*. The assortment which is prominent in stream deposits is also to be found here. The coarser sediments are deposited near the terminus of the glacier while the finer sediments are carried further down-hill.

Some outwash plains are marked with kettles and show irregular surfaces. These are called pitted outwash plains.

(ii) *Kames or kame terraces*—Regions covered with glacial drift often present more or less flat-topped, steep-sided and irregular elevations which are called kames or kame terraces. These hillocks are built of stream-borne deposits and hence show rude stratification. Their origin is believed to be due to the pouring of sediments by glacial streams from a high level or sedimentation between the valley walls and the tongue of a glacier.

(iii) *Eskers*—These are winding steep-sided ridge-like features built of stream-borne drift. This word has been derived from an Irish word meaning a path. This refers to the fact that such ridges are the only means of communication in glaciated regions which are very irregular and swampy. They are generally low in height but of considerable length. Their origin may be due to sedimentation in a subglacial tunnel. The process of sedimentation between confined valley walls referred to in the origin of kame terraces, may also produce these ridges.



Fig—35
Esker

(iv) *Crevasse fillings*—These are short ridges generally straight and are formed by filling up of crevasses by stream-borne rock debris.

(v) *Varves*—These are layered clays alternating with coarser and finer sediments. In summer and rainy seasons snow melts and water carries a good amount of sediments. The summer and rainy season sediments are coarser and the winter sediments, which are deposited in calm water are finer. These two layers of deposits therefore mark annual deposition in lakes in glaciated regions. The same episode is repeated every year so long as the lakes persist. By counting such pairs, the age of the sedimentary beds can be roughly determined.

Indicators of Glacial Action and Climate—The features related to the glacial erosion, melting, transport and deposition indicate the existence and work of former glaciers, although there may be no glacier ice at the time of observation. Among these mention may be made of the following, the origin of which has been already dealt in earlier pages.

(1) *Scratched, grooved and facetted rock fragments.*

(2) *Smooth and scratched bed rock.*

(3) *U-shaped valleys.*

(4) *Hanging valleys*—Though these may also result from rapid erosion of the main valleys by rivers.

(5) *Cirques.*

(6) *Features associated with glaciation*—Like the different types of moraines, drumlins, eskers, kames, out-wash plains and kettles.

(7) *Unassorted deposit and tillite.*

(8) *Undecomposed felspar in the drift*—In humid temperate climate the felspars change to clay but in glacial and arid climates it remains undecomposed. So it is not only suggestive of glacial climate but also of arid climate.

(9) *Absence of red ferruginous and black carbonaceous matter of the drift*—The red deposits indicate arid climate and the black carbonaceous deposits indicate temperate humid climate. So their absence indicates glacial climate.

Glacial Climates in India—Glacial climates are not rare in the geological history of India though they are infrequent. The earliest evidence of glacial action is obtained from the scratched pebbles of the Kaldrug conglomerate in South India and a Dharwar (Huronian) age has been assigned to it by R.B. Foote who examined the area.

From the rock exposures at Bap and Pokran areas in Rajasthan and Chattarpur area of Madhya Pradesh evidences of two quick and successive glaciations in the Vindhyan period have been suspected. Examination of rocks of Sidhi area of Madhya Pradesh goes to support a glaciation even in Cuddapah period (of Bijawar age).

Next evidence of glacial action is obtained from the Talchir rocks of Orissa of the Lower Gondwana (Up. Carboniferous) age. The component rocks are green laminated shales and fine sandstone, underlain by the Talchir boulder bed. The glacial action is indicated by the presence of undecomposed felspars in the sandstone, green colouring matter in the shales, and the striations and facets on the boulders. The boulder betrays a glacial climate at that period. The age of the boulder bed has been determined to be Uralian or Up. Carboniferous. This boulder bed is wide in distribution and occurs in such areas as Hazara, Simla, Salt Range (in West Pakistan), Rajasthan, Madhya Pradesh and Orissa. This is suggestive of the presence of an ice sheet in India at that time. In the Panchet beds of the upper part of the Lower Gondwana System of rocks another glacial action may be detected from the presence of undecomposed felspars in the sandstone. This is however, not so widespread as the former one. The age of the Panchet bed is Triassic. Glacial climate in Panchet time is not certain as the presence of undecomposed felspars may also indicate arid climate.

The most recent glacial climate in India occurred in the Pleistocene time. The glacial climate was more or less worldwide for the evidences of it are abundant in America and

Europe as well. Glaciers are thought to have covered the Extra-Peninsular India, but in the Peninsular part the climate was rather cold. In the Peninsular India, the evidences for this mild climate are to be sought in the effects upon the distribution of the Himalayan plants and mammals whereas in the Extra-Peninsular or Himalayan region nearly all the indicators of glacial action are present and the extinction of the Siwalik mammals also points to the same evidence. There was not an uninterrupted glacial climate in Extra-Peninsular India during the whole of the Pleistocene period. On the other hand evidences indicate that the period was marked by several warm climates intervening the cold glacial climate. In the opinion of experts there were four periods of glacial climates at that time separated by three warm inter-glacial periods.

Causes of Glacial Action—The climate of a particular area is controlled mainly by the solar radiation of heat but terrestrial factors such as latitude, altitude, ocean currrents, drift of wind, rain-fall, distance from the sea and the nature of the soil also exercise a good deal of influence. In a temperate equable climate the earth receives just the necessary amount of solar heat and it is also distributed uniformly. The more the radiation of heat from the earth's surface can be retarded the more warm will be the climate. Glacial climates are therefore explainable by either a less amount of solar heat or by an uneven distribution of it on the earth's surface. As the above mentioned factors are operating from the earliest time, the glacial climates may be the result of long continued astronomical and terrestrial factors, among which the following important ones can be mentioned briefly.

Terrestrial Factors :—

(i) *Elevation of the continental masses*—It is an observed fact that at higher altitudes the temperature is low. A fall of 1 C is noticed for every 540 ft. of altitude. This is due to the fact that the upper air is rarefied as well as without any dust particles. The cold air blowing over the snow-field lowers the temperature of the surrounding areas. The surface of a snow-field also reflects a great amount of solar heat. This will increase the size of the snow-field and the possibility of a glacial climate is greatly enchanced. It has been observed that an initial lowering of temperature by 1° C below the freezing point is capable of the final lowering of the temperature by 20° C. Moisture-laden clouds retard the radiation of heat from the earth's surface and hence cause the climate to be warm. This warming effect of the clouds is at its maximum over low lands and minimum at high altitudes. The presence of mountain masses causes rising of warm air and sinking of cold air. This affects the retardation of heat and as a consequence a lowering of temperature is effected. Then again during a glaciation period such as that of Pleistocene, a great amount of oceanic water will be locked up on the land in the form of snow and ice. This will cause a lowering of the sea level and an elevation of the continental mass. Warm sea currents are likely to be affected by the land bridges that will come into existence after the pronounced upheaval of the continental masses or lowering of the sea level. This will have a marked effect in the lowering of temperature.

An upheaval of a mountain mass is also capable of modifying the climate of a particular area by causing a general lowering of temperature by preventing the equatorial warm air from moving towards high latitude. Generally lower temperature effects are noticeable at mountain-building times. The early Proterzoic, Permian and Pleistocene glaciations were marked respectively by the Lauratian, the Appalachian and the Cascadian and the Himalayan upheavals. Uplifts of mountains may explain the sudden appearance of glacial climate but it fails to explain the rather prolonged interglacial warm climates as the elevation will continue to exist unless and until reduced by erosion or lowered by diastrophic movements. The evolution of the Rocky Mountains was not attended with glacial climate.

(2) *Polar wandering*—The wandering of poles and the shift-

ing of the earth's axis at different periods of the earth's history have been evoked at times to account for the glacial climate of a particular area, but apart from slight shifting, a change in the position of the earth's axis is dynamically impossible since the earth is as rigid as steel. The idea of continental drift carries with it a corollary of the wandering of poles to account for the variations of climate in the past but there should be some limitations to this idea of polar wandering though there is possibility of wandering of parts of the continents.

Atmospheric Factors :—

(3) *Variation in the amount of carbon dioxide in the atmosphere*—The greater the amount of carbon dioxide in the atmosphere, the more the increase in temperature and the less the amount of carbon dioxide the more the decrease in temperature, because carbon dioxide can absorb a little amount of heat. There is however no direct evidence to this assumption.

(4) *Variation in the amount of volcanic dust*—A cloud of volcanic dust will prevent the solar heat to reach the earth's surface by reflecting the solar heat. Therefore it is held that increased volcanic activity resulting in greater amount of volcanic dust in the atmosphere will cause a lowering of temperature.

(5) *Variation in the amount of moisture in the atmosphere*—The more the amount of moisture in the atmosphere, the more the increase in temperature. This is beacuse moisture laden clouds prevent radiation of heat from the surface of the earth, thus causing an increase in temperature.

The atmospheric factors produce by themselves very little effect upon the climate.

Astronomical Factors :—

(6) *Variation in the eccentricity of the earth's orbit*—The eccentricity of the orbit of the earth is variable at times. The orbit sometimes approaches a circle and sometimes a long

ellipse. Then again during the winter season of the southern hemisphere the earth is at its greatest distance from the sun i.e. at its aphelion, while during the time of summer season of the same hemisphere, the earth is at the nearest distance from the sun i.e. at its perihelion. During the period of greater eccentricity of the earth's orbit, the hemisphere in which there is winter season in aphelion will experience a longer and more severe freezing temperature thus initiating a glacial climate.

(7) *Change in the inclination of the earth's axis to the plane of the orbit*—These two are periodic factors and demand glaciation at regular intervals but records of glacial climates do not furnish any such regular periods of glaciation at intervals.

(8) *Variation in the amount of solar radiation of heat*—Solar radiation of heat varies through certain degrees. Larger variations are able to produce greater climatic changes.

(9) *Sun spot activity*—The variations in the amount of heat is greatly influenced by sun spot activity. During periods of increased sun spot activity, the solar radiation is greatly increased. This will not cause an increase in temperature but wili tend to lower the temperature as storms are frequent during the period of increased sun spot activity thereby radiating heat to a greater extent. Therefore according to Hutington increased sun spot activity will lower temperature and may initiate a glacial climate.

CHAPTER XI

LAKES

Lakes are bodies of water, either fresh or saline, in natural depressions on the surface of the earth. They range in size from a pond to the largest Lake Superior (fresh water) and the Caspian sea (saline). They abound in glaçiated regions. Some lakes are fed by rivers, others have no outlets. They are important as modifier of local climate and act as reservoirs to surplus water in streams and thus prevent the occurrence of floods. They are deposition grounds of water borne sediments and in some favourable places peat beds and bog iron ores are formed in them. They may thus be the sites of future iron ore deposits (c.f. Lake Superior iron deposits) and coal seams (c.f. some of the Gondwana coal fields) in some cases.

Formation of Lakes—Formation of lake basins due to diverse causes is in operation from the earliest time. The ancient lakes were extinguished as a result of sedimentation, crustal deformation, drainage by streams etc. The recent ones are surviving but are also liable to meet the same fate. These basins after catching water turn to be lakes. Lake basins may originate in any one of the following ways.

(1) Lakes formed by crustal movements— Basins may be formed by either faulting or folding. Due to faulting a hollow may be formed, and both faulting and folding may tilt a river valley so as to block the river to form a lake. The Pleistocene lakes of Kashmir, some of the Kumaon lakes. Lake Geneva and Lake Constance in Switzerland are examples.

(2) Some basins are the result of earthquakes as for example some of the Alpine lakes.

(3) Basins may be formed by meandering rivers. They are called ox-bow, horse-shoe or cut-off lakes. The recent Kashmir lakes are examples.

(4) Tributary river by forming a bar of sediments across the main river may block it to form lakes. Pangkong lake in Kashmir is an example.

(5) Some lakes are formed in the flood plains of rivers. As for example Lake Maurepas in the U.S.A.

(6) Rivers may form lake basins by erosion at the foot of a hill as a result of the impact of the water-fall. It may also form lakes in pot holes formed by the whirling action of stones carried in river eddies. The lakes generally come into existence after the water falls or rivers have died away.

(7) Lakes may be found to occur in depressed areas in dried up river beds as for example, the *bills* of the Ganges delta and the Manchar lake in Sind.

(8) Volcanic basins—Lakes may be formed in the crater of a volcano. The Lonar lake in the Buldana area of Bombay is an example. At times lava flows may block a river by flowipg across the river valley.

(9) Rock-fall or land-slide basins—A river may be blocked by a land slide across its valley. The Bundelkhand lakes and the Gohana lake in Garhwal are examples. The last one was formed by a land slide across a tributary to the Ganges in 1893.

(10) Solution basins—Basins are sometimes formed in sinks produced by the solution of rocks like limestone and rock salt from underneath. If the outlets of the basins be clogged with impermeable rocks, these sinks turn to be lakes. The Salt Range lakes are of this nature.

(11) Basins formed by marine action—In coastal regions sea waves sometimes build bars or spits across the coast or the mouth of a river thus converting the back water into small lagoons, which are small lakes formed in coastal regions. The Kayals of Kerala, the Pulicut lake in Madras, the Chilka in Orissa are examples of this type of lakes.

The Caspian Sea, the world's largest saline lake, was once a part of the sea and then cut off.

(12) Wind-formed basins—Basins are found in the sand dunes. The dhands or the alkaline lakes of Sind and Western Rajasthan are of this origin. Basins are also produced by wind deflation i.e. blowing away of fine particles from the surface. As these wind formed basins occur mostly in desert regions

they seldom contain any lake excepting after occasional heavy showers of rain.

(13) Glacial basins—Majority of the lakes owe their origin to glaciers. Lake basins are formed by glacial erosion by scooping of bed rocks. The Pir Panjal lakes are of this nature. Sometimes river courses are blocked by piling up of morainic matter across their valleys causing the formation of lakes. Some of the Kumaon lakes are of this nature.

Indian Lakes—Lakes are of little importance to India.

Lakes of Peninsular India—

(1) Coastal lakes—(a) Lake Chilka—It is in the Ganjam district in Orissa. This has been formed by the formation of bars or spits built by sea waves close to the coast thus converting the enclosed water into a lagoon.

(b) Pulicut lake—It occurs in the Madras district in Madras Srate. Its origin is similar to that of the Chilka lake.

(c) Kayal—Kayal is a local name in Kerala for a lagoon. Similar lakes occur in the Malabar Coast of India. Their origin is similar to that of the former two.

(2) Lonar lake—It occurs in the Buldana area of Bombay. It has a circular outline with a diameter of nearly one mile and a depth of 300 ft. The water is highly charged with sodium carbonate and sodium chloride which are precipitated in summer days.

According to one view this lake occupies a volcanic crater and according to a second view this has been formed as a result of subsidence of basaltic rocks (the Deccan traps) in a circular outline due to the escape of lava and gases from below. (PL—24).

(3) Sambar lake—This is a shallow lake which occurs in Rajasthan. During monsoon periods its area is 90 square miles and depth is about 4 ft. At other times it is dry. The saline content in Sambar lake (as well as in four other smaller lakes in Rajasthan like Puskar, Debar etc.) is due, according to Holland and Cristie, to the blowing of salts from the Rann of Cutch region by the south-west monsoon blowing over

Rajasthan. They have calculated that nearly 1,30,000 tons of salts are borne annually. This salt is dropped in various parts of Rajasthan and later concentrated to these lake basins by inland drainage. Other causes may be the former connection with the Arabian sea, marine transgression, chemical solution and precipitation in these lake basins.

(4) Dhands—These are the alkaline and saline lakes of Sind (West Pakistan) and Western Rajasthan. They are held to have aeolian origin. They contain carbonate, chloride and sulphate of sodium.

Lakes of Extra-Peninsular India—

(8) Lakes of Tibet—The largest lake in Tibet is the Koko-nor with an area of 1630 square miles. Other noted lakes of Tibet are the Manasorawar (200 square miles in area), Rakas Tal (140 square miles in area) and Gunchu Tso (30 miles to 15 miles in length). The first two are fresh water lakes and last one is saline.

Tibetan lakes have no outlets and receive inland drainage. Hence their water is getting saline every year. They are also getting smaller in area as a result of increasing desiccation. This desiccation is due to the obstruction of the monsoon winds by the Himalayas and absence of rainfall. Borax is an important constituent of the salts of these Tibetan lakes.

Their origin is attributed to blocking of rivers by piling sediments across their valleys either by tributary rivers or by glaciers. Some are due to glacial action formed by scooping out of bed rock. Some are due to the uplift of the streams by crustal disturbances resulting from the Himalayan upheaval.

(2) Lakes of Kashmir—Noted among the lakes of Kashmir are Pangkong, Tsomoriri, Salt Lake, Wular and Dal. The Wular and Dal are fresh water lakes while others are saline. The Pangkong lake in Ladakh is 40 miles long and 2 to 4 miles broad and is situated at an altitude of 14,000 ft. Tsomoriri in Rupsu is 15 miles long, 2 to 5 miles broad and is situated at an altitude of 15,000 ft. The Pangkong, Tsomoriri and the Salt lake owe their origin to the damming up of the main valley by sediments brought by tributary rivers. The

Wular and the Dal basins are thought to be hollows in the alluvium of the Jhelum River. Smaller lakes in Kashmir and neighbouring areas are called *torns*.

(3) Lakes of Kumaon—Noted among these are Naini-Tal, Bhim Tal and Khewan Tal. Their origin is thought to be due to blocking of streams, crustal movements and solution of bed rocks.

Nature of Lacustrine Deposits—Lacustrine or lake deposits present a peculiar feature in which the coarser sediments are deposited near the margin and finer sediments in the central part. Gravel beds are found in the border areas of the lake deposits and fine sandstones and shales are found in the central part. Talchir deposits of Lower Gondwana rocks in Orissa present this peculiarity.

Swamps—These are marshy grounds saturated with water. These abound in four regions—(i) flood plains, (ii) deltaic regions, (iii) recently glaciated areas and (iv) coastal regions. Swamps are important in the fact that in such areas peat is formed. Besides this these areas also supply at times diatomaceous earth which is a kind of mud with siliceous matter, the last being derived from the silica of the shells of minute plants called diatoms. This diatomaceous earth is used in the manufacture of dynamite and as an abrasive. Swamps are also very fertile especially when they are dried. Notable examples are the Dismal Swamps of Virginia and Carolina and the swamps of Sunderban in the Ganges delta in Bengal.

Peat—When fresh peat contains about 80 p.c. of water which may come down to 20 p.c. by air drying. It often contains about 2 p.c. of N_2 which may be converted to ammonia. By moderate pressure peat can be changed to a dark brown mass like lignite. With high pressure and temperature it can be changed to a coal-like substance. According to Bergius peat would be converted into bituminous coal in 8 million years under pressure and in presence of water at 50°F. It visibly contains plant materials only partially changed. At 100°C peat gives the following composition—C = 56—66%, H_2 = 5—9%, O_2 = 18—33%, N_2 = 2%, ash (inorganic salt) = 1—6%. Peat is sometimes used as fuel.

Formation of Peat—Under humid and temperate climatic conditions and in stagnant and shallow water bodies, such as lakes and lagoons, formation of peat generally takes place. In such environment with oxygen, the plant debris cannot be changed to higher ranks of coal. When the plant remains undergo decay humic and ulmic acids are formed. Bacterial activity is mainly responsible for this change. The acids and water containing oxygen destroy the bacteria later and the decay of the plant materials is retarded considerably. Thus slow decomposition of the plant debris takes place and peat is formed at last. It is most abundant between 35—60°N latitudes where the temperature is generally 40 to 60°F.

Depending on heat, pressure, nature of accumulation basins and plant materials many chemical changes take place, when carbon and hydrogen separately combine with oxygen (hydrogen combining more rapidly than carbon). This produces a gradual carbon enrichment as the process continues.

Occurrence of Peat in India—At present peat-like substance is under active formation in the Sunderban area of South Bengal in the Ganges delta and in the Nilgiri Hills in South India. The former is called low level peat because it is formed very near the sea level while the latter is called high level peat because its formation is taking place at an altitude of 6000 ft. Peat is also found at a depth of 20 to 30 ft. below Calcutta intermixed with sand and loam. Exaamination has revealed the presence of very little moss but abundance of the remains of trees like Heritiera littoralis (Sundri trees), Willows, Cypress, Phragmites, leaves of Ficus cordifolia (fig), seeds and leaves of other trees. The volatile matter is present to the percentage of 50 to 60 and moisture 15 to 20, In the marshy Sunderban area peat is formed from the remains of Sundri trees mostly and also of other types of vegetation. Vegetation here differs from that of the Nilgiri area where Spagnum, Heath, Erica, Scirpus, Carex etc. are the main types of vegetation.

Peat is also found under the Indo-Gangetic Plain at several places.

Bog Iron Ore—Certain valuable iron ore deposits, owe their origin to a result of the activity of certain types of bacteria called iron bacteria and chemical precipitation. These bacteria are very minute organisms which precipitate iron from the solution of iron compounds and oxidise it. One of the soluble compounds of iron is ferrous carbonate ($FeCO_3$), specially in water containing CO_2 (c.f. $CaCO_3$). But there is a limit to the solution and concentration of $FeCO_3$. When that limit is reached, $FeCO_3$ begins to precipitate out. If there be available oxygen it is oxidised and precipitated in the form of Fe_2O_4 and $2\ Fe_2O_3$, $3\ H_2O$. At the bottom of swamps or lakes where there is not much oxygen, iron is precipitated as $FeCO_3$. How far the process is aided by bacteria and how far it is chemical it is difficult to say.

CHAPTER XII

DIASTROPHISM AND DEFORMATION OF THE EARTH'S CRUST

Movements of major parts of the earth's crust resulting in regional crustal deformations, either in vertical or horizontal or in any inclined direction, are known as *diastrophic movements* and the phenomenon in which such changes are brought about by these movements is known as *diastrophism*.

There are two types of earth movements—(i) *epeirogenic* and (ii)—*orogenic*. The word epeirogenic has come from the Greek words *epeiros* meaning a *continent*. Epeirogenic movements give rise to the elevations and depressions of continents and hence such movements are called continent making movements. Such movements are radial movements of the earth's crust. The rising areas of continents are known as *positive areas* and the sinking areas are known as *negative areas*.

The word orogenic has come from another Greek word *oros* meaning a *mountain*. Orogenic movements give rise to mountains and hence the name. Such movements are tangential to the earth's surface.

Diastrophic movements, comprising the epeirogenic and orogenic types of movements produce displacements which may be in the vertical, inclined or horizontal directions producing elevation or subsidence of an area, folds, faults, or tilting of strata. These movements determine to a large extent the area and elevation of a particular place. The epeirogenic movements are rather sudden compared to the orogenic movements which are very slow. The epeirogenic movements generally accompany some sudden catastrophic changes and phenomena like faulting, earthquakes and the like, and their effects are clear and pronounced in the shore regions.

Epeirogenic movements—Such movements have their effects upon the sea level which is either raised or lowered relative to the land surface. Measurements of elevations and depressions are generally made from the mean sea level which is the mean level between high tide and low tide marks. Changes in position of this sea level relative to the land arecalled *eustatic changes* which produce conspicuous effect on the shore regions. Somewhere the coastal regions are elevated and somewhere these are depressed, Such eustatic changes are due either to the changes in the capacity of the sea-basin or in the volume of sea water of both. The characteristics of a shore line of subsidence have already been stated under the chapter on oceans. It should be remembered that such changes in vertical directions involving relative displacement of land and sea are entirely different from the extension of land into sea by marine construction or extension of the sea towards land by marine destruction. Some notable examples of changes produced by diastrophism will here be discussed.

Examples of Elevation of Land—At present there are more examples of elevation than those of subsidence. This is probably due to the post-glacial changes. An oft-quoted example of elevation is furnished by the Temple of Jupiter at Serapis near Naples in Italy. There are three columns of marble each about 40 ft. high. These columns are bored to a height of 20 ft. from the base by some types of rock boring marine animals like Lithodomus. These testify to the fact that after these columns were built there was a subsidence to at least about 20 ft. when the boring animals bored the columns. Then there was an uplift which elevated the columns again above the sea level. In recent times the area is again subsiding.

Another remarkable example is the elevation of the Island of Palmarola in the Adriatic Ocean. It was elevated 210 ft. nearly in 70 years, from 1822 to 1892 i.e. at the rate of 3 ft. per year.

The shore regions of Norway and Sweden also show clear signs of uplift. This is due to the changes from post-Pleistocene deglaciation.

Indian examples of elevation are furnished by parts of both the east and west coasts of the Peninsular India. Raised beaches, wave cut benches, emerged coral reefs etc. are often seen in several parts of these two coastal regions pointing to the uplift of these areas.

Evidences of inland elvation can not however be so clearly obtained because there is no convenient reference line but extensive surveys will show the effects of elevation and depression in the interior parts of the continents as well.

Examples of Depression of Land—The temple at Serapis, near Naples can also be cited as an example to this point. Drowned river valleys, fiords and submerged forests are features associated with the submergence of a coastal area.

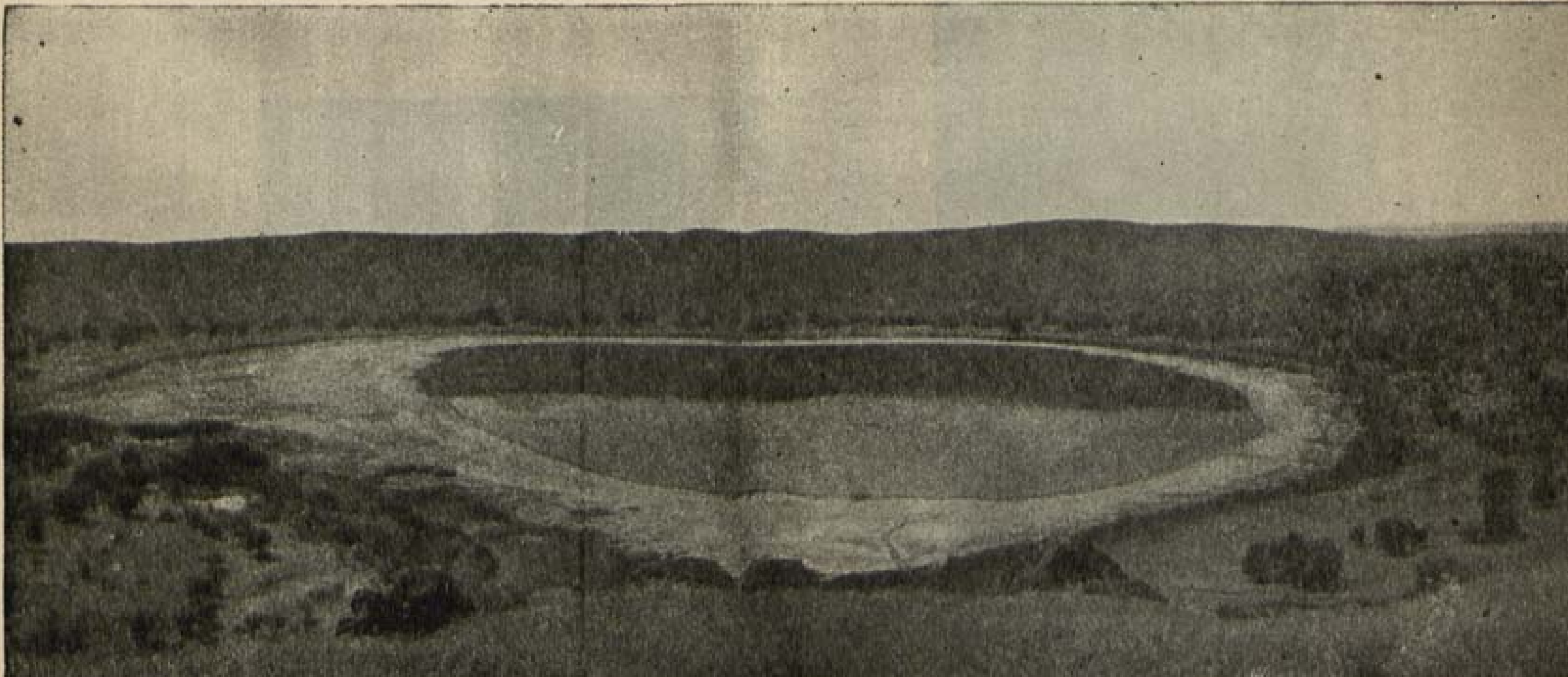
The submerged forests of Bombay and Pondichery coasts are examples of submergence of the coastal region of India. The submerged forest of Bombay is nearly 20 ft. below the mean sea level. The trees occur with their roots in the soil of the submerged area. Peat beds in the Ganges delta are also examples. It should be remembered in the case of the submerged forest that tree trunks may be drifted and being heavier at the bottom due to the roots, will assume a vertical position after settling as is the case in some coal seams. If the roots also extend into the soil as well, then they are examples of submergence of an area.

The causes of these vertical movements are possibly due to isostatic adjustments following glaciation and deglaciation but isostasy fails to account for opposite movements in adjacent areas. Tne thermal cycle hypothesis put forward by Joly may account for such movements.

Crustal Deformations and Associated Structures :—

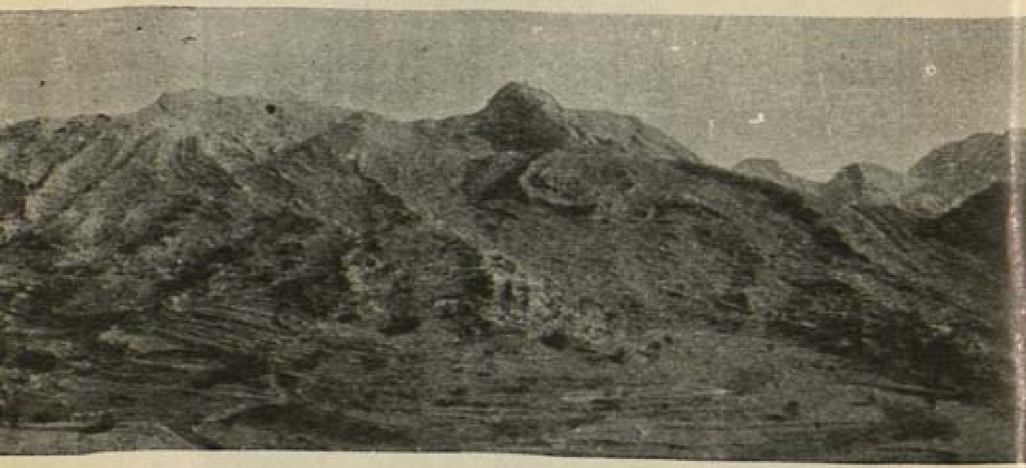
Movements of the parts of the earth's crust are always occuring and their cumulative effects are producing pronounced results. Stresses set up by continued straining produce deformation of the crust when the rocks can bear no more straining. Distinct structural features result from these deformations which form the subject of discussion of this chapter.

Several terms, such as outcrop, dip and strike, will be first

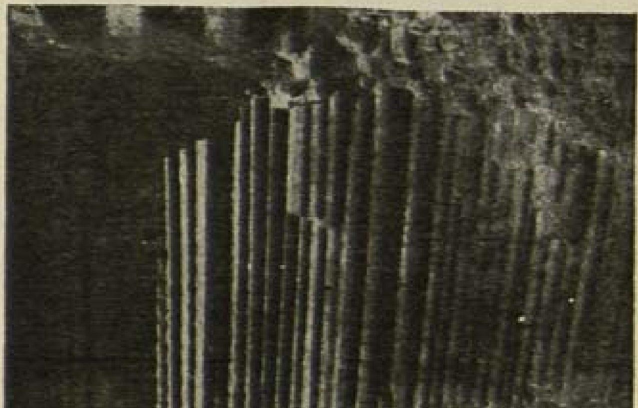


Pl.—24 A panoramic view of the Lonar Lake in Buldana, Bombay

(By courtesy, Director, G.S.I.)



Pl.—25
Overfold in Krol Rocks (*By courtesy, Director, G.S.I.*)

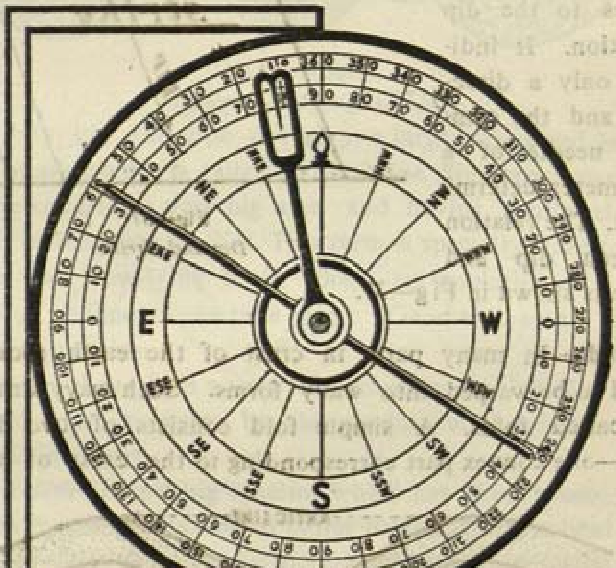


Pl.—26
Culumnar Joints, Andheri

dealt before coming to the proper subject as these will often be used in later pages.

Outcrop—This denotes the area over which a particular bed is exposed upon the surface. The line of intersection of the bounding surfaces of a bed with the surfaces of the earth, marks the limit of it.

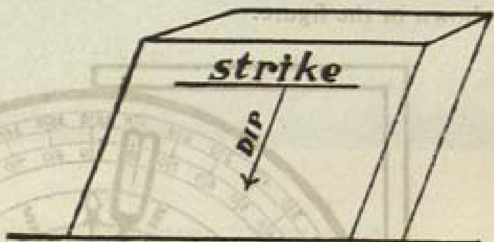
Dip—It is the inclination of a bed with the horizontal plane. The angle is generally measured by an instrument called clinometer and is expressed in degrees with the direction e.g. 25 degrees S.E. A simple form of a clinometer is shown in the figure.



Fig—36
Clinometer-Compass

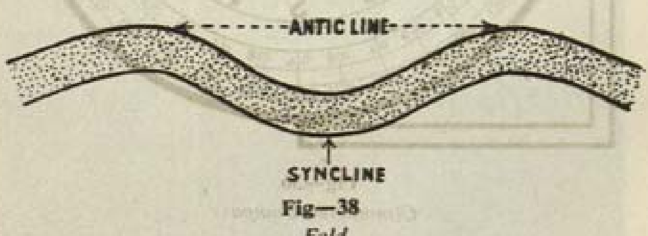
Clinometer-Compass—In its simple form, the instrument consists of a pendulum which moves over a disc graduated in degrees and divided into four quadrants each reading from 0^{0} to 90^{0}. There is a magnetic needle at the centre of the disc which moves over a bigger concentric circle which is graduated from 0° to 360°. There is another small concentric circle which is divided into sixteen parts to give the geographical directions. The clinometer has a stand by means of which it can be placed over an inclined rock and the deviation of the pendulum from 0° gives the amount of the dip and the direction is obtained from the innermost smaller circle.

Strike—It is the horizontal line of extension of a bed and is given by the intersecting line between the bed and the horizontal plane. Strike is at right angles to the dip direction. It indicates only a direction and the compass needle of a clinometer determines it. The relation between dip and strike is shown in Fig—37.



Fig—37
Dip and Strike

Folds—In many parts in crust of the earth rocks are found to be warped into wavy forms. Such wavy structures are called folds. A simple fold consists of two distinct parts—one convex part corresponding to the crest of a wave



Fig—38
Fold

and the other concave part corresponding to the trough of a wave form. The crest part of a fold is called an *anticline* and the trough part is called a *syncline*. The accompanying figure will illustrate the form.

Repetition of beds on a map generally represents folding of strata though this may also be due to erosion or faulting. It must be remembered that anticlines and synclines reflect structural features of the crust and not outward surface forms because erosion may make an elevated hill from the synclinal part and a depression from an anticlinal area as shown in Fig. 39

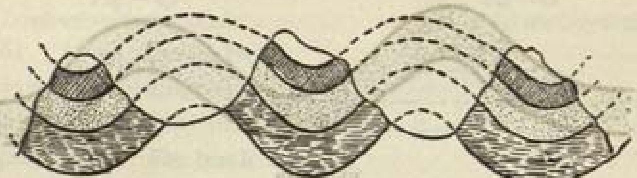


Fig.—39
Effect of erosion upon folds

A very big anticline covering a large region and having gently sloping sides is called a *geanticline*. Similarly a very big syncline covering a very big area and having gently sloping sides is called a *geosyncline*. This term is specially used to denote a vast low-lying basin where accumulation of a thick deposit of sediments can take place. Geosynclines are future sites of mountains.

Anticlinorium—It is a very big anticline which has been rendered more complex by the production of minor folds in the anticlinal part.

Synclinorium—It is a big syncline which has been made more complex by the production of minor folds in the synclinal part.

Dome—It is an upwarp structure corresponding to the crest of a wave form which does not extend over long distances. Domes may be produced by localised earth movements. Dome-like structures also result from spheroidal weathering as in the case of Archaean rocks of India (C.f.—Dome Gneiss) Dome-like structures may also result from the accumulation of lava materials from volcanoes or by the intrusion of salt material in plastic state near the surface of the earth.

Basin—It is a trough-like structure which does not extend over a long distance. The dip of the beds or the slope of the sides is almost radial towards the centre (just opposite to the dome structure). These result from earth movements of comparative minor intensity. Basin-like structures may also result from differential erosion.

Different Types of Folds :—

(1) *Symmetrical folds*—This is the simplest type of folds in

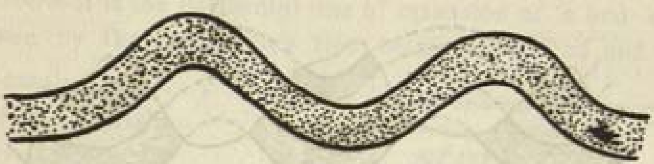


Fig.—40
Symmetrical folds

which an anticline or a syncline is symmetrical about the median plane. This is also called the Jura type of folds.

(2) *Asymmetrical or inclined folds*—In this type of folding

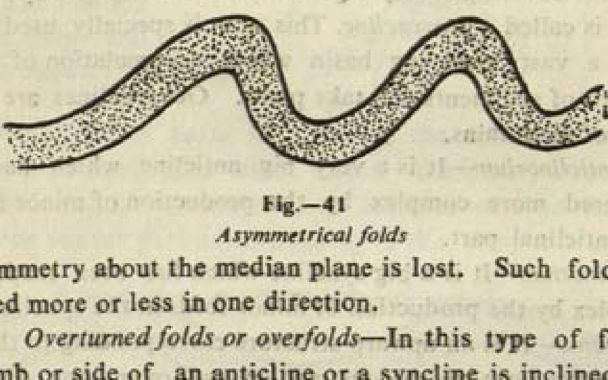


Fig.—41
Asymmetrical folds

the symmetry about the median plane is lost. Such folds are inclined more or less in one direction.

(3) *Overturned folds or overfolds*—In this type of folding one limb or side of an anticline or a syncline is inclined to a great extent towards the other (PL—25).

(4) *Recumbent folds*—This type of folding shows one limb practically resting on another and the two limbs are more or less in a horizontal position.

In an *overthrust*, part of a folded bed is broken and is carried to a great distance. This is a case of faulting though it is produced at a late stage of folding formed by extreme compression.

(5) *Isoclinal folds*—This type of folds shows parallel limbs which may either be vertical or inclined.

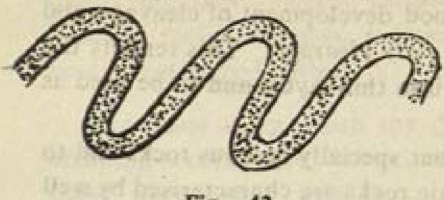
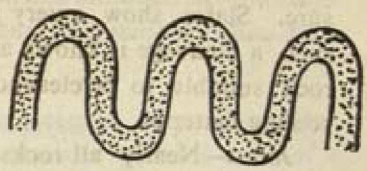


Fig.—42
Isoclinal folds (inclined).



Fig—43
Isoclinal folds (vertical)

(6) *Monocline* — In this type of folding the strata are bent in one direction only. On both sides of the bend the strata are horizontal.

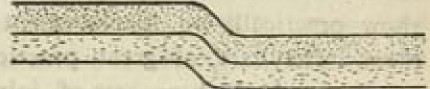


Fig.—44
Monocline

(7) *Homocline*—If there are several beds all dipping in one direction, the resulting structure is called a homocline.

(8) *Pitching fold*—The median line of an anticline or a syncline is its axis. If this axis is inclined to the horizontal plane, the fold becomes a pitching fold and the angle between the axis of the fold and the horizontal plane is called the pitch of the fold.

Fig—45
Pitching fold

Outlier—It is an exposure of an younger bed surrounded by outcrops of older formations. The formation of an outlier is mostly due to erosion but may also result from faulting. The hills in Fig. 39 show outliers.

Inlier—It is an exposure of an older bed surrounded by outcrops of younger formations. As in the case of outlier, it is also due mainly to erosion but may also result from faulting. The valleys in Fig. 39 show inliers.

Cleavage—This indicates in a mineral or a rock easy planes of separation. Minerals and rocks possessing cleavage will break more easily in cleavage directions than in others. Good cleavage does not exist in all minerals and rocks. In minerals it is due to the molecular structure and in rocks it is due to the parallel arrangement of minerals mostly by pressure. Slates show a very good development of cleavage and such a cleavage is known as *slaty cleavage*. This renders the rock suitable to be cleaved into thin layers and to be used as roofing material.

Joints—Nearly all rocks but specially igneous rocks and to some extent some metamorphic rocks are characterised by well developed cracks which are called joints. Joints are common features in rocks like granites, basalts, limestones etc. Joints show practically no displacement of rocks on both sides of them. They are of great practical importance in quarrying. Granites show three sets of joints mutually at right angles. Such joints are called *mural joints*. Basalts show joints which are closely spaced and enclose hexagonal columns. Such joints are called *columnar joints* and are specially exhibited by the basalts of Giant's Causeway of Northern Ireland and of the Isle of Staffa in the Hebrides off Scotland. In India similar examples are obtained from Andheri near Bombay and from Gujri on the Bombay-Agra Road near Maheswar. (PL—26).

Joints which are parallel to strike directons are called *strike joints*. Those which are parallel to the dip directions are called *dip joints*. Strike and dip joints are only seen in folded and inclined rocks.

Joints which traverse rocks for considerable distances are called *master joints* in contrast to *minor joints* which are of short lengths.

Joints are caused as a result of contraction due to cooling or consolidation of rocks. Sometimes they are also caused by compression or by tension.

They control underground percolation of water and thus determine the water supply at a place and underground solution of rocks. They thus influence weathering processes and determine to a large extent the surface features of a region.

Faults—This is the phenomenon in which there is relative displacement of rocks along the breaking plane. The displacement may be instantaneous or a bit delayed. Their effects are most clear in bedded rocks although all the three kinds of rocks—igneous, sedimentary and metamorphic, may be dislocated by faulting.

The plane along which the displacement takes place after breaking is called the *fault plane.* Strictly speaking it is not a plane surface but may be curved or otherwise irregular. Hence it is better to be called *fault surface.* Such fault surfaces are apt to be highly polished because of the frictional resistance offerred to the displacement of rocks. Such a smoothed and polished fault surface is called *slickenside.* Sometimes the fault surface is full of angular fragments which are produced from both sides by faulting. This is known as *fault breccia or crush breccia.* In the extreme case of crushing the fault surface is marked by a thin deposit of clayey matter which is called *gouge or flucan.* Lower or upper ends of the strata which are involved in faulting are sometimes bent in upper or lower directions. This bent structure produced at the ends of strata by faulting is known as *drag.* As already stated faulting produces relative displacement of rocks. The result is that one part is put to a higher position relative to the other & this may produce a mountain like structure with a steep side. This is called a *fault scarp* (PL—28). This cliff-like part is later modified by erosion. The overhanging part is called the *hanging wall* and the other part is called the *foot wall.*

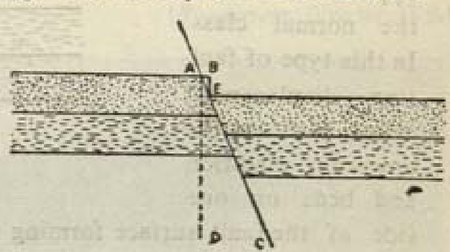


Fig 46
Fault

AB denotes the horizontal displacement and is called the *heave.* BE is called the *throw* which denotes the vertical displacement. It may be in the upward or down ward direction. Angle CAD is known as the *hade* of the fault. It is the angle which the fault surface makes with the vertical plane. The angle CAB, which the fault surface makes with the horizontal plane, is called the *dip* of the fault. AE which denotes the displacement of a strata is called *displacement or slip.*

Different Types of Faulting :—

(1) *Normal fault*—In this type of faulting, beds on one side of the fault surface forming the hanging wall goes down, after breaking, relative to the other. This is also called the gravity fault.

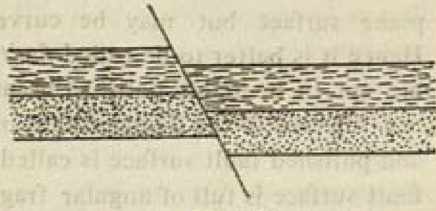


Fig 47
Normal fault

In this type of faults the hade is towards the down throw side.

(2) *Reverse (or Reversed) fault*—It is so called as this type of faulting is just the opposite to that of the normal class. In this type of faulting displacement takes place in the upward direction and beds on one side of the fault surface forming the hanging wall are pushed up the fault surface. The hade is here towards the upthrow side.

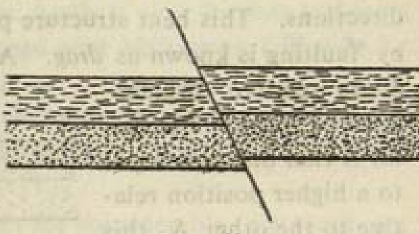
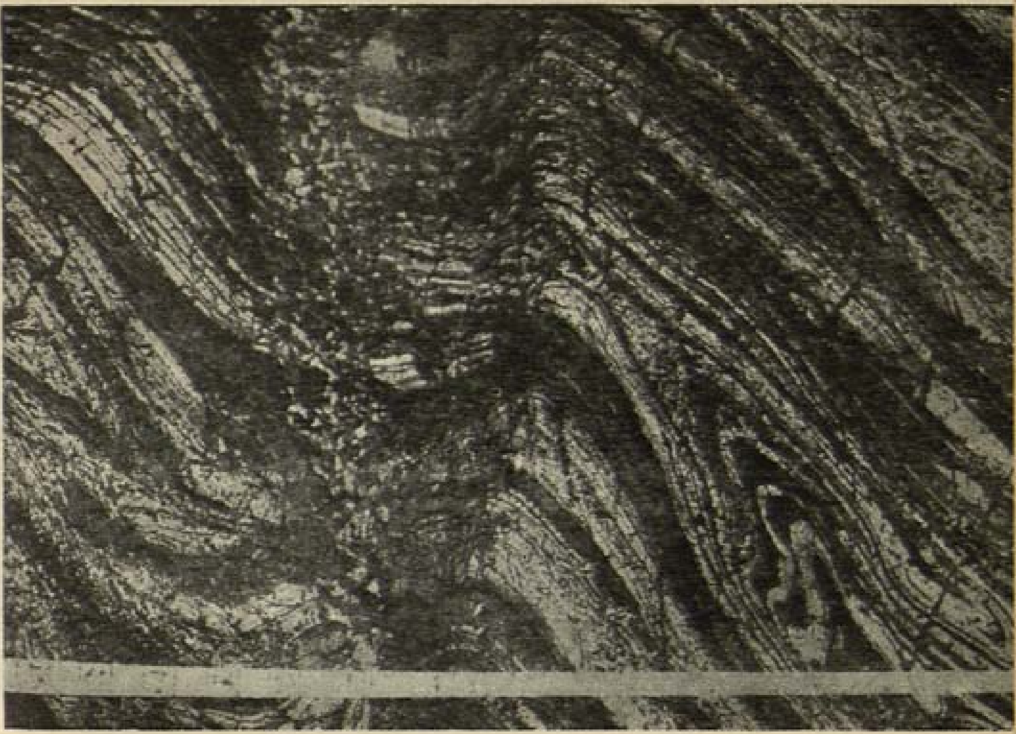


Fig 48
Reverse fault

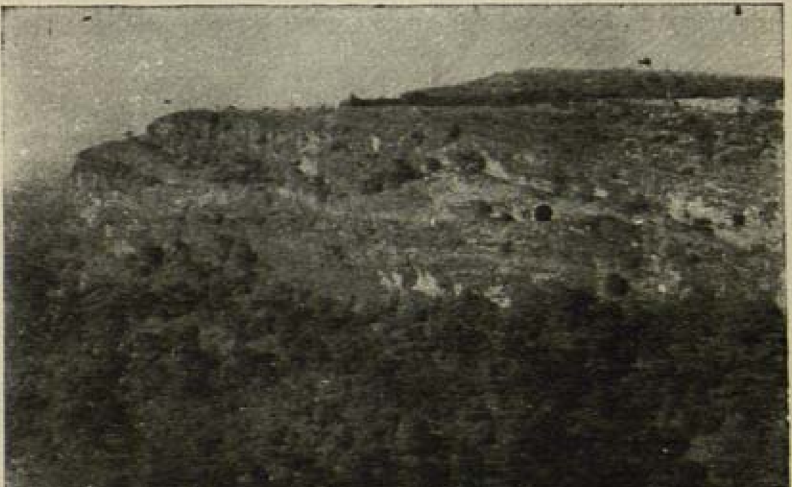
(3) *Dip fault*—This is a type of faulting in which displacement takes place in the dip direction. This type of faulting cuts directly across the strike of the strata involved in faulting.

(4) *Strike fault*—In this type the faulting takes place in the strike direction of the strata involved. The strike of the fault and that of the strata are parallel.



Pl—27 Folding and faulting with fault breccia, Kurhadi Nadi, Raikela

(By courtesy, Director, G.S.I.)



Pl.—28

Reverse fault in Up. Kaimur Rocks

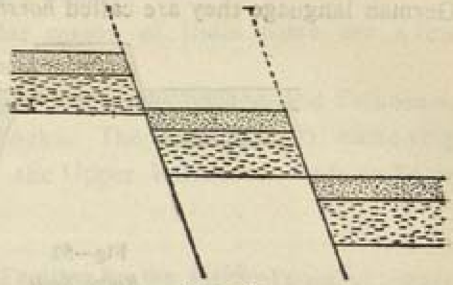
(By courtesy, Director, G.S.I.)

Pl.—29 A view of the Kanchanjungha from Sikkim (*By courtesy, Director, G.S.I*)

Pl.—30 Volcanic agglomerate, West Spur of Dalma Hills (*By courtesy, Director, G.S.I.*)

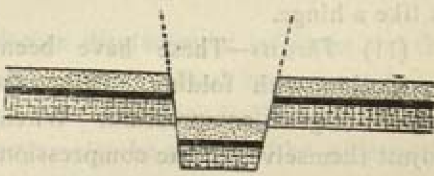
(5) *Oblique fault*—This type shows displacement across the strike of the strata in any direction.

(6) *Step fault*—Faults may be grouped together in an area. Several parallel normal faults all producing throw in the same direction, will make a stair-like aspect. Such a type of faulting is called step faulting.



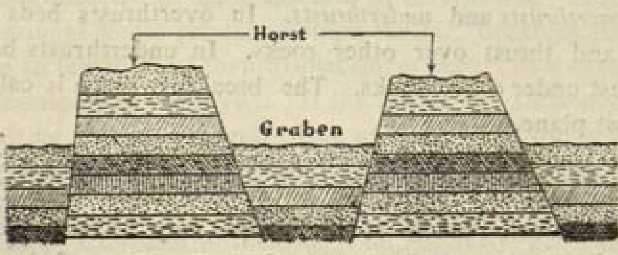
Fig—49
Step fault

(7) *Trough* (*or Trench*) *fault*—If there be two series of step faults which converge or tend to converge, the resulting structure is the formation of a trough or a trench. Hence this type of faulting is called trough faulting or trench faulting. In German language the trough or trench so produced is called *graben.* If the troughs extend to great distances and have considerable magnitude they are called *rift valleys,* as for example the Rift Valley of East Africa.



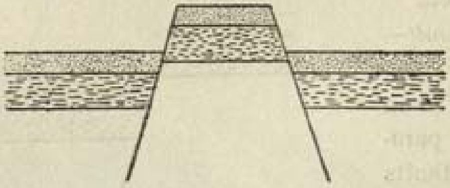
Fig—50
Trough fault or Trench fault

(8) *Ridge fault*—If there be two series of step faults which diverge, the resulting structure is the formation of a ridge.



Fig—51
Horst and graben

Such a type of faulting is therefore called ridge faulting. In German language they are called *horsts*.



Fig—52
Ridge fault

(9) *Rotary fault (Also called scissors fault)*—Faulting is sometimes attended by a sight pivotal motion thus producing down-throw at one end and an up-throw at the other end of the strata. Such a type of faulting is known as a rotary fault.

(10) *Hinge fault*—It is a type of faulting which shows displacement at one end but the other end remains at its original place. The name is so because the structure produced is like a hinge.

(11) *Thrusts*—These have been already mentioned in connection with folding. These are generally frequent in regions of great compression. When the beds can no longer adjust themselves to the compressional forces, breaking takes place and this results in the formation of low angled faults in which the relative displacements of beds are very wide. Such types of faults are called thrusts. They are conspicuous features in regions of fold mountains. Thrusts are of two kinds—*overthrusts* and *underthrusts*. In overthrusts beds are broken and thrust over other rocks. In underthrusts beds are thrust under other rocks. The breaking plane is called the thrust plane.

Nappe is a French term which is used to denote rock sheets brought forward by a thrust or by a recumbent fold. Due to subaerial erosion much of the nappe may be eroded at a later date but here and there a few exposures of the old nappe may be seen which have escaped erosion. Such part of a nappe is called a *klippe* (a German term meaning cliff).

Erosion may expose rocks below a nappe mass. Such an eroded rock gap is called a *window*.

In the Extra-Peninsular region of India there are a few well studied nappe regions.

In Simla region the Krol nappe has pushed the Palaeozoic rocks over the Tertiary rocks. The lower Tertiary rocks crop out as windows through the Upper Palaeozoic beds in Solon and Subathu areas.

Signs of Folding and Faulting in the Field—Detailed observation in the field can only detect folding and faulting. The following may prove useful.

In favourable sections folding can be easily detected. From the wavy surface in a region folding may be detected. If a bed dips in two opposite directions folding is the inference. Sudden changes in the thickness of beds may be the result of folding and faulting too. On the map repetition of beds means folding though this may also be produduded by erosion.

Faulting with its relative displacement of rocks and the drag can also be seen at some places. Faulting can not be so easily detected as folding. In some cases fault scarp may indicate faulting but scarps may also be produced by differential erosion.

Causes of Folding and Faulting—Compressional forces acting tangentially to the surface of the earth are responsible for the production of folds and also of reverse and thrust faults. Tensional forces produce normal faults. Breaking takes place due to tension and then displacement occurs as a result of the attraction due to gravity. If the forces be suddenly applied faulting is the general effect whereas if the forces be slowly applied folding may take place. Folding and faulting are however manifestations of the forces which are deep-seated in nature. Continental drifting, radio-actively generated heat, convection currents in the subcrustal regions, isostatic adjustment etc. may be the ultimate causes.

CHAPTER XIII

MOUNTAINS AND THEIR ORIGIN

Mountains may be generally divided into three types—(i) *Accumulation type*, (ii) *Relict or Residual type and* (iii) *Deformation type*.

The agencies involved in mountain-making processes are (i) *volcanic activity*, (ii) *differential erosion or* (iii) *crustal movements*. Commonly two or more processes combine to produce complex results.

Accumulation of volcanic materials such as lava etc. into heaps or cones produce volcanic mountains. Such mountains and sand dunes are examples of accumulation type of mountains.

Differential erosion may cause the formation of mountains This is specially noticeable in regions which are composed of materials of differing solubility. Plateau remnants are the examples of relict type of mountains. (Plateau is an elevated area generally over 1000 ft. in height with a more or less flat top. They are of two types—(a) *volcanic plateau* as for example the Deccan Plateau, and (b) *erosion plateau* as for example the Chotanagpur Plateau in Bihar.)

The deformation type of mountains can again be divided into two types—(a) *fault type* of mountains and (b) *fold type* of mountains.

Fault mountains are produced by both normal and reverse type of faulting. They are also called *block mountains*. Sometimes adjacent faults may produce an intervening raised ridge and adjoining low-lands. Such raised parts and depressed areas are called *horsts and grabens* respectively. The Fig.—51 illustrates the idea.

By far the most important type of mountains is the fold type. In the formation of fold type of mountains several distinct stages are noticed which are :—

(a) Initial stage—When the accumulation of sediments in a subsiding geosyncline takes place.

(b) Youth stage—When the sediments are strongly folded and faulted.

(c) Mature stage—When the surface features are impressed by erosion.

The first stage in the formation of a mountain is the existence of a long trough of shallow depth of water, which is called a geosyncline.

Into such a trough sediments are brought from the sides and deposited. With continued sedimentation the floor of the geosyncline begins to sink down under the load of sediments. When the floor sinks down the two sides approach each other and thereby the trough becomes more deepened. With the narrowing of the trough and sedimentation, the geosynclinal trough becomes nearly filled. There is a limit to the sinking of the geosyncline because the upper lighter material can not sink down to indefinite depth into the lower heavier material. After some time the subsidence stops and with the narrowing of the floor the sedimentary piles are thrown into folds. Folding and thrust-faulting take place and as a result a complex fold system of mountains originates. The uplift is due to isostatic adjustment, compressional force; expansion, due to heat, of the geosynclinal material that has gone down etc. Later the agents of erosion sculpture the elevated mountain mass and form peaks, valleys etc. with the production of the grandeur of a typical mountain. With the lapse of time the mountain mass will be eroded completely, unless crustal movements oppose the levelli ng action of the eroding agents, and the sediments deposited into basin may again form a mountain at a later period. In this way the mountain making cycle may be perpetuated.

Ultimate Causes of Mountain Building—Compressional forces are responsible for the formation of the fold type of mountains which is the most common type of mountains. Various explanations and ideas have been put forward to account for the uplift of the mountain masses. They are :—

(1) *Contraction hypothesis*—This states that the earth

through radiation of heat, is cooling and as a result the earth will shrink and wrinkles will be developed on its surface just as a mango, if left exposed to heat, will shrink and develop wrinkles upon its surface. But with the discovery of the fact that the radio-active substances generally produce heat on disintegration, this idea has lost much of its popularity.

(2) Some hold that under the load of sediments the floor of the subsiding geosynclinal basin, is likely to be broken and thus sediments would meet the internal heat and would expand in volume, as a result the upper sedimentary layers would be uplifted. This process, if in operation, would account for the vertical uplift only but not the compressional forces. This may come into operation during the late stage of mountain-building.

(3) When the geosynclinal basin, on receiving the sedimentary load, will sink down, the two sides of the shallow trough will be brought nearer. This will generate compressional forces and may account for the formation of fold mountains.

(4) Isostatic adjustment is believed to play an important part in mountain-building but the process only accounts for vertical uplift and not the compressional forces. Its part, though considerable, may be held to be subordinate.

(5) Continental drift hypothesis accounts well for the mountain-building processes. The equator-ward force according to Wegener is responsible for the origin of the Alpine-Himalayan chain of mountains and the west-ward force is responsible for the formation of the Rockies and the Andes.

(6) *Thermal Cycle Hypothesis*—Joly is the propounder of this hypothesis. He states that the sial block is floating over the simatic layer. This layer of sima contains an appreciable quantity of radio-active elements. These elements are such as they spontaneously disintegrate by emitting rays and are changed to some other element. Lead is commonly the final product. During this transmutation a great amount of heat is generated. The sial block is even richer in the content of radio active elements. It is believed that there is a rapid fall in the

content of radio-active elements with depth. This may be due to the fact that radio-active elements might have been carried by volatile matters along with the residual magma forming the upper granitic sial layer. The radio-active elements inspite of their high atomic weights were thus carried upwards during the differentiation of the earth's silicate layer into acid, intermediate and basic rocks during the condensation of the earth. This radio-actively generated heat in the sial layer compensates much of the loss of heat by radiation at the earth's surface and the heat generated in the simatic layer goes on accumulating. As a result it will ultimately melt rocks at that particular place of accumulation. The density of the rock material of that place will then decrease and the upper sial block will sink down in the molten sima. The accumulated heat escapes in course of time through the floor of the oceans and the sial block is buoyed up. Again with accumulation of heat the sial block will sink in the sima and again with the escape of heat it will rise up. This cycle which is controlled by radio-actively generated heat is called Joly's thermal cycle after the name of the propounder. This also offers an explanation for the cause of mountain-building. During the melting of the sima, the sial layer will be in a state of tension and with the escape of heat, shrinkage of the sima, due to solidification, will start and the sial layer in order to accomodate itself to the shrinking simatic layer will be thrown into folds.

(7) *Convection Current Hypothesis*—According to Holmes there is a convection current from the equator to the poles in the subcrustal region which causes crustal deformation responsible for mountain-building. The radio-actively generated heat in the simatic layer will make it molten and will allow the flow of convection currents.

Igneous Activity during Mountain Building—Formation of complex fold mountains is generally associated with the intrusion and extrusion of magma. The magmatic intrusion and extrusion may be due to the increase and reduction of pressure as a consequence of the uplift of the sedimentary pile. Batholiths of granite are generally associated with complex fold mountains. These granitic cores are sometimes laid bare by deep erosion. The batholiths are generally associated with sills, dykes etc. the formation of which is due to the intrusion of magma into the planes of weakness in the mountain rocks. Sometimes even extrusion of magma takes place with the resultant volcanic activity.

The Himalayas—The Himalayas extend from the Indus bend on the north-western part to the Brahmaputra bend on the north-eastern part of India. These are series of parallel mountain chains separated by valleys or plateaus. The width varies from 100 to 250 miles whereas the length is nearly 1500 miles. The mountains have clear geological and structural affinity with the Baluchistan and Burmese mountains.

Division of the Himalayas .—

A. Geographical Section.

(1) Transverse section according to Burrard—

(a) The Punjab Himalayas—Length 350 miles from the Indus bend near Gilgit to the Sutlej River. Nanga Parbat (26,620 ft.) is the highest peak in this part of the Himalayas. The Pir Panjal is a southernly branch from it.

(b) The Kumaon Himalayas—Length 200 miles from the Sutlej River to the River Kali. Nanda Devi (25,645 ft.) is the highest peak here. Other noted peaks are Trisul (23,360 ft.), Badrinath (23,190 ft.), Kedarnath (22,770 ft.), Gangotri (21,700 ft.) etc. The Ganges originates from the region near Gangotri. The Dhauladhar Range is the southern branch from it.

(c) The Nepal Himalayas—Length 500 miles from the River Kali to the River Teesta. The highest peak of the world Mount Everest (29,141 ft.)[1] is situated in this part. It was named after Sir George Everest, once Director-General of the Survey of India. Other noted peaks here are

1. A recent (1954) survey gives Mt. Everest a height of 29028 $\pm$ 10 ft.

Kanchanjungha (28,146 ft.), Dhaulagiri (26,795 ft.), Gosianthan (26,291 ft.) etc.

(b) The Assam Himalayas—Length 450 miles from the River Teesta to the Brahmaputra bend near Namcha Barwa Noted peaks are Namcha Barwa (25,445 ft.), Kula Kangri (24,784 ft.) etc.

(2) Longitudinal section—

(a) The Outer Himalayas or the Siwalik Hills—Width varies from 5 to 30 miles; average height 3000 ft. This region is swampy and forest-clad as for example the Duars in North Bengal and Terai region in Nepal.

(b) The Lesser or Middle Himalayas. Width varies from 40 to 50 miles. Height varies from 12,000 ft. to 15,000 ft.

(c) The Great or the Central Himalayas—The average height is 20,000 ft. The highest peaks occur in this region.

(d) The Trans-Himalayas or the Tibetan Himalayas—Average width about 25 miles. It contains river valleys at altitudes of 14,000 ft.

B. Geological Sections : Longitudinal section based on geological structure and age of the component rocks. They do not exactly correspond to the geographical longitudinal sections.

(1) The Outer or the Siwalik Himalayas consisting of Tertiary rocks only.

(2) The Lesser or the Sub-Himalayas consisting of rocks of Pre-Cambrian to Tertiary age. These are separated from the Siwalik rocks by the Main Boundary Fault. The region is highly complicated due to overthrusting.

(3) The Central or the Main Himalayas consisting of crystalline and metamorphic rocks of Purana (Algonkian to Torridonian) age.

(4) The Tibetan Himalayas consisting of marine fossiliferous rocks of Cambrian to Eocene age.

Structure of the Himalayas—The structure of the Himalayas is not quite known because of the fact that much of the Himalayan area is yet unexplored. Our knowledge of the

Himalayas is due to several expeditions and the work of some geologists noted among whom are Dr. Pilgrim, Dr. West, D.N. Wadia, Dr. J. B. Auden, H. H. Hayden, R. D. Oldham, S. Burrard etc. The eastern part of the Himalayas, from Kumaon eastwards, is practically unknown. This is due largely to the inaccessibility to the place and inclemency of the climate. In the eastern part the Himalayas rise abruptly from the plain and attains high altitude near the plain practically. The foot hill zone is very narrow. In the western part however the Himalayas rise slowly from the plain and the highest region is quite at a great distance from the plain. The western part of the Himalayas shows the following structural belts—

(1) Outer and Sub-Himalayas—A zone of Tertiary rocks. It consists of two belts :—

(a) *Siwalik belt*—consisting of river deposits of Mid. Miocene to Lower Pleistocene age. This persists throughout the foot-hill region of the Himalayas and shows simple types of folding.

(b) *Sirmur belt*—This persists from Naini Tal north-westwards. It is absent east of Naini Tal. It is made up of old Tertiary lagoon deposits which show isoclinal folds.

The Siwalik belt is separated from the older rocks by the Main Boundary Fault.

(2) Central Himalayas—

(c) *Autochthonous belt* (i.e. occuring at the same place)—This consists of rocks of the age of Carboniferous to Eocene and shows recumbent folds in which these rocks have overrided the Tertiary rocks to the south. In the western part of the Himalayas, these overfolds are of Eocene rocks with Carboniferous to Triassic core such as the Panjal Volcanic rocks or the Krol rocks. In the eastern part Lower Gondwana strips are overfolded on the Siwaliks.

(d) *Purana nappe belt*—Unfossiliferous slate rocks are overthrust on the autochthonous belt in the western part.

(e) *Crystalline nappe belt*—It is composed of crystalline and highly metamorphosed older rocks with granitic intrusions of various ages. This belt represents the root zone of the nappes. They are also overthurst on the autochthonous and Purana belts.

(3) Trans-Himalayas—

(f) *Trans-Himalayan or Tibetan belt*—It consists of marine fossiliferous rocks of Cambrian to Eocene age in the Tethyan basin with a few breaks. It shows simple folds but a portion has been overthurst on the crystalline, Purana and autohthonous belts in Kashmir area.

Each of these structural belts is separate from the next one by a thrust plane of a recumbent strike fault that dips northwards. It has caused the older northern rocks to override on the younger southern rocks.

In the structure of the Himalayas the following peculiarities are to be noted—

(1) The *general strike* of the mountains is NW-SE. The strike of the folds is parallel to this direction.

(3) The *syntaxial bends* at NE and NW Himalayas. There are two bends of the Himalayan chain of mountains, one occuring at NW part near the Nanga Parbat and Gilgit just where the Indus takes a bend, and the other occuring at the NE part in the Mishmi country in Assam where the Brahmaputra takes a bend to the south. At the NW corner the general strike of the mountains changes from NW—SE to South first and then to the SW. The folded mountains take a knee-bend turning at this point. Similarly at the NE corner the strike bends to the south. These two bends are called syntaxial bends. These are due to the under-thrust of the wedge-like masses of the Peninsular India into the Tethyan sediments which made the Himalayan chains.

(3) *Arcuate disposition*—The convexity is towards the Peninsular India and concavity towards Tibet. Peninsular side is steeper while Tibetan side shows gentle slopes.

(4) The *Main Boundary Fault*—This is a series of reversed strike faults throughout the length of the Himalayas. This marks the boundary between the Siwalik rocks and older ones. The Siwalik rocks are confined generally (with a few exceptions) to the south of the main boundary fault and the

older rocks to the north of it. This marks, so to say, the boundary of these two types of rocks. Hence is the name. Their reversed nature has made the superposition of strata reverse with the younger ones resting below the older, i.e. the Siwaliks resting under the Sirmurs and the Sirmurs resting under still older rocks. This is a conspicuous feature of the outer Himalayas.

(5) *Transverse gorges*—These are deep gorges cut by some Himalayan rivers just across the mountain ranges. They have been discussed in greater detail in the drainage system of the Extra-Peninsula (Chapter VI).

Origin of the Himalayas—The origin of the Himalayas is a history of the formation of a complex fold system of mountains. In the Mid. Palaeozoic time there were two huge continents—one Gondwanaland in the southern hemisphere comprising Brazil, Guinea, Uruguay, Africa, Madagascar, Peninsular India, Western and Central Australia and Antarctica and the other Laurasia in northern hemisphere comprising Central and Eastern Canada, Greenland, Fenno-Scandia, North and Central Siberia, North-East of Siberia and probably Southern China and Indochina. These two continental units were separated by an east-west running ocean which received the name Tethys of which the present Mediterranean Ocean is the remnant. The Tethys varied in extent and depth from time to time. Sedimentation from the Gondwana side and Lauratian side was going on in the Tethyan basin from the earliest time. The evolutionary history of the Himalayas followed the same episode as a fold system of mountain follows.

According to Eduard Suess, a noted Austrian geologist, the pressure, leading to the uplift of the pile of sediments in the Tethyan basin to the Himalayan height, came from Tibetan side while the Peninsular India on the south remained passive. This seems quite plausible from the arcuate disposition of the Himalayan chain of mountains, the convex side of the arc being towards Peninsular India. But P. Lake has shown from the arcuate disposition of the mountains facing the Pacific Ocean in the east coast of Asia, that Central Asia, seems to flow in the eastern direction also. The simultaneous movement of the Central Asiatic mass to radial directions is unacceptable. Moreover Central Asia is a region of excess of matter whereas if the radial movement is to be accepted, it ought to have been a region of deficiency of matter. The only explanation which can be accepted is that the Penninsular India has made an underthrust in the north towards the Central Asia thereby uplifting the sediments of the Tethyan basin and originating the Himalayas.

The Tethys was obliterated in the Tertiary period. The uplift of the Himalayan mass was effected by four great impulses. The first came in the Upper Eocene time, the second in Middle Miocene, the third in Upper Pliocene and the fourth in late Pleistocene. The second upheaval was the most powerful of these four. The Tethys was practically obliterated after this but a linear trough throughout the length of the foot of the Himalayas remained where the Siwalik system of rocks was formed. After the third upheaval this disappeared also. The fourth one was rather weak in comparison with the former ones. Minor earth movements occurred in recent times. The Himalayas are still rising.

The Indo-Gangetic Plain :—

Physiographically India can be divided into three regions— 1. *Peninsular India,* 2. *Indo-Gangetic Plain and* 3. *Extra-Peninsular India or Himalayan region.* The second includes the vast fertile alluvial tract of the Indus, the Ganges and the Brahmaputra systems. The rest of India, excluding the Indo-Gangetic Plain and the Himalayan region comes under the Peninsular India.

The Indo-Gangetic Plain covers nearly half of Assam, most of Bengal, parts of Bihar, practically the whole of Uttar Pradesh and the Punjab, Northern Rajasthan and most of Sind. It spreads over an area of nearly 3,00,000 square miles. Width varies from 90 miles in the east to 300 miles in the west. The depth is maximum between Delhi and the Rajmahal Hills in Bihar but is quite shallow in Bengal and Assam. The depth is estimated to be nearly 6,000 ft. or a bit more from geodetic conclusions. Borings have reached more than 2,000 ft. but have not got the rocky bottom. This alluvial tract is composed of Pleistocene and recent deposits of clay and sand with occasional peat beds. Two ridges have been made out under the alluvium—one is the Delhi Ridge which is an extension of the Aravalli strike and the other is in direction of Delhi and the Salt Range. Kirana and Sangla are the outliers of the last one.

Origin—According to Suess the Indo-Gangetic Plain has been formed by the filling up of a depressed area which was formed as a foredeep in front of the upheaved Tethyan sediments. According to this view massive Peninsular India remained passive and offerred resistance to the southernly advancing pile of sediments as a result of the pressure from the northern Tibetan side which caused these foredeeps. These deeps were later filled up by sediments carried from both the northern newly upheaved Himalayan side and the southern Peninsular India.

According to Sydney Burrard, late Surveyor General of India, the Indo-Gangetic depression is of the nature of a rift valley. A rift valley is a structure bounded longitudinally by parallel sides and is formed by the faulting of a huge linear tract between two parallel fault lines. Sedimentation into such a rift valley has produced the Indo-Gangetic Plain. This view has got few geological evidences in favour and is based only on geodetic observations.

According to a third view the Indo-Gangetic Plain has been formed by the filling up of a basin of the nature of a geosyncline. Continued sedimentation was increasing the load and the basin was sinking concurrently as a result of isostatic adjustment. This subsidence has given rise to the enormous thickness of the sediments. This is quite in keeping with the geological processes.

Other Mountain Ranges of India—Extra-Peninsular Region.—

Karakoram—Starting from the Tibetan Plateau, (the highest plateau in the world with an elevation of 16,000 ft.), if we proceed southwards we shall meet a number of ranges in succession. These mountains are more or less parallel to the Himalayan chain. First we shall meet the Karakoram Range. This starts from the Pamir Plateau (elevation 12,000 ft.), west of the Tibetan Plateau. The Hindukush Mountain to the north of Afghanistan also starts from the same Pamir Plateau and is more or less in continuation with the Karakoram Range. The Karakoram carries the world's second peak—the K_2 or the Mount Godwin Austen with an altitude of 28,250 ft.

Kailash Range—As we proceed southwards we shall come across first the Aling Kangri, then the Trans-Himalayan Range and the Kailash and the Ladak Ranges. Occuring in the middle portion to the north of the Himalayan Ranges, the Kailash and the Ladak Ranges are closely spaced mountains. This region is notable as the ultimate source of the three important Indian rivers, namely the Indus, the Ganges and the Tsang Po (the Brahmaputra). After these two ranges come the Zanskar Range and finally the Himalayas proper.

The North Western Mountains—These are the mountains separating India from Baluchistan. These Baluchistan ranges are the Sulaiman, the Bugti and the Kirthar Ranges (from north to south). Their strike is transverse to the trend of the Himalayas. The Salt Range of the N.W. Punjab is also more or less parallel to this line of ranges.

South Eastern Mountains—These ranges start from the Himalayas with the Patkoi Hills and continues through the Naga Hills and the Manipur Plateau. There is a westernly branch associated with it. It includes the Jaintia, the Khasi and the Garo Hills. The first branch after the Manipur Plateau continues to Lushai Hills and the Arakan Yoma. (Yoma means a bone-like ridge.) The Arakan Yoma continues upto Cape Negrais but is traceable upto the Andamans, Nicobars and Sumatra.

Peninsular Mountains :—

The Aravalli—This is the oldest mountain range in India. It divides Rajasthan into two parts—one north-western part and the other south-eastern. The trend of the Aravalli is NE—SW. It extends from Gujrat to Delhi but its extension is perceptible into the Laccadives and the Maldives. It is also believed to have extended beyond the Himalayas. Though situated in the way of south-west monsoon, blowing from the Arabian Sea, it can exert very little meteorological influence as it is parallel to the monsoon course. As a result parts of Rajasthan are gradually turning to be desert. It now reaches the highest elevation of 4,000 ft. nearly but in former times it was much higher. The mountain consists of the Aravalli and the Delhi Systems of rocks which are of Huronian and Algonkian age respectively. It was originated as a result of the orogenic movements at the close of the Dharwar time (Huronian) and was upheaved again in later periods probably in Mesozoic time.

The Vindhyan Mountain—This consists of a line of scarps on the southern border of the Central Indian highlands from Indore to Bagelkhand. Rising to an altitude of 2,500 ft. to 4,000 ft. this mountain is composed of rocks of the Vindhyan System (Torridonian). The rocks are mostly sandstone, limestone and shale. The eastern part of the Vindhyan mountain, in Bagelkhand, is known as the Kaimur Range. The trike of the mountain is ENE-WSW.

The Satpuras—Situated in the region between the two rivers, the Narbada and the Tapti, there are several parallel ranges (also parallel to the Vindhyan Mountain) which are called the Satpuras. They start from the Rajpipla Hills in Bombay on the west and extend almost to Bihar. It consists for the most part of the Deccan basalts but other types of rocks also occur in places, such as the Gondwana rocks in the Mahadeva Hills (from Keuper to Rhaetic age) and Archaean rocks in the Maikal Range.

The Eastern Ghats—This is a series of broken and unconnected mountains running from Orissa to the Nilgiri Hills bordering the Bay of Bengal. The Eastern Ghats are relict type of mountains. Notable among the series are the Nallamalai, the Shevaroys and the Nilgiri Hills. Individually the mountains do not show uniformity in component rocks and are of the same geological age. Archaean rocks (Khondalites, Charnockites, and gneisses) and Cuddapah rocks are the most important ones. The general strike is NE—SW. These hills have a coastal plain made up of alluvium which has been formed by the sea waves from these mountains and the coastal area. The north-east monsoon brings rain in winter here. The rainfall is scanty.

The Western Ghats—(Also called the Sahyadris)—The word ghat has come from the peculiar step-like character as a result of weathering of the horizontal layers of the Deccan basalts which cover the major part of the Western Ghats from Goa to the River Tapti. The Western Ghats extend from the Tapti to the southernmost Cape Comorin. The Western Ghats meet the Eastern Ghats in the Nilgiri Hills. Here the rocks have been replaced by the Archaean gneisses (the Charnockites). The Nilgiri Hills reach the second altitude in the Peninsular India in the Dodabetta Peak with an elevation of 8,760 ft. South of the Nilgiri Hills, the Western Ghats after a gap, called the Palghat gap, continue through the Anaimalai Hills having the highest elevation in the Peninsular India in its Anaimudi Peak (8,850 ft.) and the Cardamom Hills to the south. The Cardamom Hills throw off an easternly branch—the Palni Hills. The general strike is more or less N-S. There is a very narrow coastal tract in front of the Western Ghats. This is due to the rigour of the destructive action of sea waves. The rainfall here is considerable due to the obstruction of the south-west monsoon by the Western Ghats.

The Rajmahal Hills—These form an isolated range of high and detached hillocks. The Rajmahal Hills cover an area of 80 miles' length and 30 miles' breadth. The averag e altitude is 1500 ft. The constituent rocks are basalts with intercalations of grits, carbonaceous shale and calcareous and siliceous materials in small quantity.

CHAPTER XIV

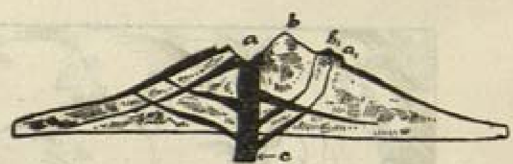
VOLCANOES AND VOLCANISM

Volcanoes are hill-like masses formed around a pipe by the accumulation of molten rock materials and fragmental rocks which are the products of volcanic eruptions. Successive explosions caused by volcanic activity are liable to break the solidified cover and surrounding rocks. The products of explosions accumulate round the pipe through which the molten material or lava, as it is called, forces its way up. The result is that a cone is gradually built up round the pipe. Such conical hill-like masses, formed as a result of explosions and accumulation of the products of explosive activity, are called *volcanoes*.

Fig—53
Volcanic eruption

The explosion accompanied by the pouring out of lava and volcanic gases and blowing of surrounding rock fragments is called a *volcanic eruption*. Volcanoes, which erupt very often, are called *active* volcanoes. Those which show eruptions with the lapse of considerable period between the consecutive eruptions are called *dormant* volcanoes. Dormant volcanoes are likely to show eruptions in near future, while other volcanoes which do not show any volcanic activity within recorded periods of history are known as *extinct* volcanoes. It is impossible to say whether a volcano is extinct or lying in dormant stage as great lengths of time often lapse between consecutive eruptions.

Volcanoes vary in height from the smallest with scarcely 100 ft. height to the Cotopaxi in Ecuador with a height of 19,600 ft.—the highest active volcano in the world. Some extinct volcanoes rise to more heights as the Chimborazo (20,500 ft.) in Ecuador and the Aconcagua (23,000 ft.) near Chile. Some oceanic volcanoes particularly those near the Hawaiian Islands in the Pacific Ocean rise from below the sea level and attain a height of 14,000ft. above the sea level. Adding this to their depths below the sea level, the total height will be over 30,000 ft. that is more than that of the loftiest mountain of the continents.



Fig—54
Volcano

Description of a Volcano—A typical volcano is generally conical in shape. The slope may be gentle at times and steep at other times. At the top of the cone (b) there is a circular pit which is called the *crater* (a). Its diameter varies from a few hundred feet to several miles. The formation of the crater and the volcanic cone is due to the accumulation of the products of explosive volcanic eruptions. The larger fragments of rocks fall near the pipe or the mouth and form gradually a conical ridge round the pipe. As a result, the central region becomes depressed to form a crater. This cone and crater structure is very typical of a volcano. An ideal section will show a pipe or conduit (c) in the central region through which lava makes its way upwards. On its way upwards lava sometimes cuts across the country rocks as dykes instead of taking the usual central pipe. This may be due to either clotting of the former lava and the presence of fissures or planes of weakness in the surrounding rocks. These dykes on coming to the surface also form cone and crater structure at times. These cones are called secondary or parasitic cones (a_1, b_1). Lava sometimes also spreads laterally into the country rock in the form of sills, specially if the country rock be sedimentary. Sometimes at the top of a volcano a huge, more or less circular, pit is found. Such pits are called *calderas* from Spanish source. This pit is to be distinguished from the volcanic crater though the volcanic crater itself may form a part of it. Where as the formation of a crater is due to unequal accumulation of volcanic products round the mouth, the origin of calderas is due either to the explosive violence of volcanic activity resulting in the blowing up of the summit of the volcanic cone or due to the subsidence of a tract along circular fractures as a result of emptying of magma below. The former type of calderas is known as the *explosion caldera* and the latter type is known as the *subsidence caldera*. By the absence of volcanic products in the surrounding region the subsiding origin of a caldera can be inferred. The true nature of a caldera can thus be made out.

Products of Volcanic Activity—Volcanic eruption ejects rock fragments molten lava and volcanic gases.

Solid products—The rock fragments formed by volcanic eruption are called pyroclastic materials or simply *pyroclasts*. These fragmental materials are formed by the explosive violence of volcanic eruptions. The explosive violence of a volcano depends upon the nature and the composition of the magma. If the magma be viscous, it will clot over very easily between successive eruptions and with the next explosion a great quantity of fragmental material will be thrown up. This viscosity of magma again depends upon the chemical composition and the volatile content. Acidic magmas are more viscous than the basic ones. Consequently with acidic magmas fragmental products are more frequent than with basic magmas. The presence of gases lowers the viscosity of magma, but the volatile content is absolutely necessary for the explosiveness. Materials are supplied by the country rock from the side regions of the volcanic cone. Particles of liquid lava are also blown up which after solidification add to the fragmental products. These pyroclastic materials vary widely in size and weight from very minute and light materials to materials as heavy as several hundred tons. These materials have been classified according to size. The bigger angular fragments are known as *volcanic blocks.* If the bigger fragments be somewhat rounded instead of being angular, they are called *volcanic bombs* because of their resemblance to bombs. Their rounded appearance shows their origin from liquid lava. The bombs often present a cracked appearance due to the nearly solid state of the material from which they have been formed. These are known as bread crust bombs as their surfaces present the appearance of a bread. Smaller fragments are called *lapilli* (from a Latin word meaning little stone) or *cinders.* Still smaller fragments are called *volcanic sand, volcanic dust* and *volcanic ash* sucessively. The volcanic dust and ash when consolidated form a rock which is known as *tuff.* The finest particles are often blown to great distances from the volcano by wind. The ashes that fall near the volcanic cone are often washed down by heavy showers of rain which generally accompany volcanic eruptions. The result is the formation of mud flows. The city of Herculaneum was buried under mud flow following an eruption of the Vesuvius.

The pyroclastic materials are at times very spongy and vesicular in appearance which is due to the escape of gases from the magma out of which the products result. While escaping, these gases often carry little particles and consequently the resultant mass assumes a sponge-like apearance. Several types of pyroclastic materials result in this way. *Pumice* or *Pumice stone* represents the extreme stage of vesicular structure. The magma in this case is so charged with gases that their escape to the atmosphere produces a froth-like product which is extremely light. This froth-like rock material forms a variety of rocks which is called pumice or pumice stone. More generally occuring is the vesicular mass called *scoria*.

The little spaces are gradually filled up by other materials and they assume almond-like shapes. These infillings are called amygdales and the resulting structure is called *amygdaloidal* structure.

The heterogeneous mass of pyroclastic material when more or less consolidated is called *volcanic agglomerate* or *volcanic breccia* (PL—30). The individual fragments are more or less angular. It is to be noted that the soil derived from these rock fragments are highly fertile.

Liquid products—The liquid rock material ejected by a volcano is called *lava*. After the explosive violence has died down, pouring out of lava takes place. The main path of ascension of lava is the volcanic pipe but it also penetrates into the surrounding country as dykes and sills. This is especially the case in the upper region of a volcanic cone as the volcanic cone is not a firm and consolidated region. On the other hand it is formed of loose rock fragments of volcanic activity.

Lava erupted by different volcanoes and at different times varies greatly in chemical composition. Effusive type of granite is called rhyolite, that of syenite is trachyte, that of gabbro is basalt, while those of diorite are called dacite and andesite. The chemical composition of lava is a very important factor in the viscosity of the lava, in the rate of flow and ultimately in the texture and surface features produced from it. The more siliceous ones are more viscous than the basic ones. The basaltic lavas are therefore more fluid and travel to greater distances while the rhyolitic type will have very slower rate of movement and will cover less area. In the case of very fluid magma the lava, even after solidification at the upper surface, may be liquid inside. Consequent draining out of lava will make a tunnel which is called a *lava tunnel*. The more viscous lavas are piled up near the volcanic pipe and form domes of lava and plug-like volcanic necks. The latter stand as pillars after the erosion of the surrounding loose pyroclastic materials that formed the volcanic cone. The slope of the ground is also a factor in the rate of flow of lava.

The composition of lava influences the nature of eruption as well. There are two types of eruptions—one is the *central* type and the other is the *fissure* type or *mass* type of eruptions. The central type of eruption is that in which the eruption of lava comes out from a central vent whereas in a fissure eruption the ejection of lava takes place from a long fissure or a group of parallel or closed spaced fissures. The lava erupted in the former case is of acidic composition, where as in the latter case it is of basaltic composition, is highly fluid and spreads over a great tract of land covering the former surface features. The Deccan trap of Peninsular India is a notable example of this fissure type of eruption. The Deccan trap covers a tract of 200,000 square miles and is 10,000 ft. in maximum thickness. The feeding fissures are filled up at a later period and solidify to form dyke-like masses.

The chemical composition also determines the colour of the resulting rocks. Acidic lavas will produce light coloured rocks whereas basic lavas produce dark coloured rocks.

The texture of the resulting rocks is also influenced by the viscosity of the magma and therefore ultimately by the chemical composition.

Lava on solidification produces different types of surface features which also depend upon the chemical composition of it. Viscous lava presents, after solidification, rugged and rough surface which is formed by the breaking up of the solidified crusts by the motion of the still liquid region below. The resulting mass is called *block lava*. The more fluid lava produces ropy or wavy and smooth surfaces after consolidation. This type of lava is called *ropy lava*. The ropy lava starts with a higher temperature than the block lava.

Pl.—31 Mud Volcano, Yegubwat, Burma.
(*By courtesy, Director, G.S.I*)

Pl.—32 Central Cone of Barren Island Volcano.

(*By courtesy, Director, G.S.I.*)

Basic lava, such as the spilitic type, often presents a peculiar surface feature resembling pillows when poured into water.

It is to be remembered that chemical composition is also always influenced by the volatile content of lavas which also forms a part of the composition.

The temperature of a lava varies from 1000°—1200°C and is maximum at the upper surface. This is because of the oxidation or other types of chemical actions with gases and other materials at the surface.

Gaseous products—The influence of gaseous products upon the melting point, viscosity and fluidity of magma, the rate of cooling and the resulting texture and vesiculation has already been stated. These gaseous products always accompany volcanic activity.

Steam forms the most important constituent of volcanic gases and contributes nearly 90 p.c. of the total content of volcanic gases. Huge amount of steam rises upward in the form of clouds from a volcano. This steam after cooling in the upper atmosphere causes torrential rain. The-atmospheric content of water vapour also adds to it. Such torrential rains are frequent after volcanic outbursts and are responsible for the formation of dangerous mud flows already referred to. Observations reveal that Mount Etna emits 460,000,000 gallons of water from one of its secondary cones.

Other gases are carbon dioxide, nitrogen, sulphur dioxide, hydrogen sulphide, hydrogen, sulphur, chlorine, ammonium and sodium chlorides, carbon monoxide, hydrocarbon gases, boric acid gas, boron compounds, fluorine and phosphorous vapours, arsenic vapours and compounds.

At higher temperatures gases like fluorine, hydrochloric acid vapour, sodium chloride vapour, boron compounds and phosphorous vapour are given off. With falling temperature the gases that come out are sulphur compounds, arsenic compounds etc. and carbon dioxide comes last.

Structures Associated with Volcanic Activity :—

Structural features such as dykes, sills, volcanic necks, lava tunnels, volcanic cones, calderas, parasitic cones etc. have been already referred to. Here are some more associated structures.

Cinder cones—These conical structures are built round a volcanic pipe by the accumulation of the loose fragmentary materials, mostly cinders. Variable amount of ash is always associated with it. The angles of repose vary with ash and cinders. Ash comes to rest at an angle of nearly 30^0 while the cinders come to rest at an angle 45^0. The steepness of the cone varies therefore with the nature of the material. The coarser material will form steeper cones while the finer products will produce low and gently sloping cones. These cinders and ash cones are generally associated with explosive types of erosion. They are smaller in area and more or less round in ground plan.

Lava cones—These cones are in contrast to the former ones. They have gently sloping sides and they cover wider areas. Such cones are built up by quiet type of eruptions by the piling of lava flows one upon another.

Shield volcano is a term which is used to express the very gently sloping lava cones covering wide areas because such lava cones resemble a warrior's shield in appearance, with the central region being slightly convex.

Viscous lavas on the other hand are likely to form dome-shaped masses with steeper sides round the pipe.

Composite cones or Mixed cones—These are intermediate in character and composition between the cinder cones on the one hand and lava cones on the other. They consist of layers of pyroclastic materials with intercalations of lava flows. During the explosive phase fragmental products are blown off and these accumulate round the pipe. During the quite phase of eruption lava piles are poured over these fragmental materials. Such a combination will produce a composite cone. The nature of the volcanic products and the coarseness of the materials determine the steepness of the sides and the area of the cones. Due to rude stratification present in such volcanoes they are also called *strato-volcanoes.*

It sometimes happens that in the cones or calderas of old volcanoes small cones and craters have been formed due to continued volcanic activity. These small cones and craters exactly look like primary volcanic cones and craters, and perform the same function. The Vesuvius, built in the caldera of Monte Somma, is a noted example to this point. The inner cone and crater generally go on increasing in size, ultimately this small cone and crater will exactly gain the size of the original cone and crater of the old volcano. When this stage will come the volcano will be called a *rebuilt volcano*.

Explosion pits—These show in miniature the performance of volcanic activity. In such cases the volcanic activity has only blown up holes and built small cones round the holes. They often form crater lakes. These explosion pits are known as *maars*.

Volcanic plateau—The former structures are associated with the central type of eruptions but these volcanic plateaus are associated with the fissure eruptions. They result from the piling up of lava flows one after another to enormous thickness extending over very wide areas. The Deccan Plateau of Peninsular India is an example.

The following ones are some structures and phenomena which are intimately connected with volcanic activity or which are frequent in volcanic areas.

Fumaroles—The word fumarole has come from a Latin word *fumare* meaning "to smoke." These are fissures or vents through which volcanic gases are ejected. It has been stated previously that a huge quantity of gases accompanies every volcanic eruption. But even after volcanic eruptions, when a volcano remains temporarily inactive or dormant, the volcanic gases are ejected through the volcanic pipe as well as through numerous other fissures and exit holes. These fumarolic gases are very hot and sometimes reach temperatures as nearly as 650°C.

The fumarolic gases are practically the same as the volcanic gases already stated. Steam here also forms the major part and contributes nearly 99 p.c. of the total volume. Other gases are carbon dioxide, hydrochloric acid gas, chlorine vapour, sulphur dioxide, hydrogen sulphide, hydrogen, some hydrocarbon gases such as methane, nitrogen, hydrofluoric acid vapour and boric acid vapour. Fumaroles emitting sulphurous vapour are called *solfataras*, when emitting carbon dioxide they are called *mofettes* and when emitting boric acid vapour they are called *saffioni*. The changes brought about by the reaction with the country rock is called *pneumatolysis.* The more important agents in bringing these changes are fluorine, boron, hydrochloric acid and hydrofluoric acid vapour. The compounds produced are calcium fluoride, apatite, tourmaline etc. Fumaroles also produce some metallic compounds in the volatile state notably as chlorides, fluorides etc. By the decomposition of these fumarolic gases by means of heat or by reaction with the country rocks and these gases or by the mixing of two or more gases, various metallic compounds are produced. These are compounds of iron, lead, copper etc. In 1817 in the Vesuvius region a crack of 3 ft. width was found to be filled with specularite (a scaly variety of hematite). Its formation may be due to the action of the two gases, steam and ferric chloride, according to the following chemical reaction— $Fe_2Cl_6 + 3H_2O = Fe_2O_3$ (specularite) $+ 6HCl$.

Galena is also found in the Vesuvius region. Its formation is due perhaps to the reaction between lead chloride and hydrogen sulphide.

$$PbCl_2 + H_2S = \underset{\text{(galena)}}{PbS} + 2HCl.$$

The most remarkable fumarolic field is the Valley of Ten Thousand Smokes near Mt. Katami in Alaska. It is a natural wonder. Through the fissures of this valley steam and other gases are constantly pouring out.

Apart from the metallic content the fumaroles are important as supply centres of huge amount of steam which may be utilised in generating power. Fumarolic areas of Tuscany, Java, Celebes etc. have produced satisfactory results to this point.

Hot springs—These are fissures or holes through which hot water escapes to the surface. Like fumaroles they are also abundant in volcanic regions, although some are situated in highly crumpled rocks which are faulted or folded. The temperature of the water is varying from that of warm water to that of boiling water. This water generally comes from subsurface water that gets heated in contact with the increased temperature below. Magmatic water may also contribute to a little extent. This is proved by the fact that with seasonal change, the flow of the hot springs also changes. In the rainy season hot springs remain active whereas in the winter and summer seasons i.e. during the dry seasons they turn out to be fumaroles by emitting only heated gases. The heat may be due to some exothermic reactions or radio-activity as radio-active substances are often present in such sprin gs.

Rajghir near Patna and Sitakund near Monghyr in Bihar, Vakreshwar in Birbhum in West Bengal, Lasudra and Vajrabai in Bombay and Manikarna in Kulu and Jwalamukhi in Kangra in Punjab (I) and Tatapani in Poonch in Jammu and Kashmir are noted hot springs.

Waters from hot springs are sometimes highly charged with other materials. These waters carrying a good amount of volatile contents are good solvents of materials. Hence on their way upwards these waters take into solution considerable quantity of soluble materials from the country rock and reaching the upper surface deposit these materials round the supplying holes. Water containing carbon dioxide takes into solution calcium carbonate or limestone. When this water comes upto the surface it deposits the calcium carbonate around the mouth and a cone-like structure or encrustation will be made. This type of calcareous deposit is called *tufa* or *travertine*. When the water contains alkali matters in solution it can take into solution silica which may be deposited afterwards on the surface. Such deposits are called *siliceous sinters*. Such deposits are light and white or gray. Other substances like borax, alum, and sulphur and arsenic compounds are found in such waters.

Geyser—This is a form of hot spring which emits gases and hot vapours at intervals. The eruption of water is remarkably regular and periodic. The classical example is afforded by the Old Faithful geyser in the Yellowstone Park so named because it is faithfully discharging water at average intervals of 65 minutes for many years though it has now become a bit irregular. The height of the water column varies from a few feet to hundreds of feet. In the case of the Old Faithful it is generally 150 ft. The intervals between two consecutive eruptions of water and the duration of the eruption are also variable. They are rather rare and occur only notably in Iceland, New Zealand (Pohutu in New Zealand is the geyser with the world's highest throw of water), Yellowstone Park and California in the United States of America.

At the geyser vents cones are made of deposits from the geyser water. Such deposits are called *geyserite*. Sometimes there are mere encrustations. Every geyser possesses some peculiarity with respect to the interval between consecutive eruptions, the duration of eruptions, height of the water column, etc. These peculiarities are due to variations in heat, water supply and the nature of the feeding pipe.

Bunsen in Iceland, and Allen and Day in the Yellowstone National Park have worked on the periodic eruptions of water from the geysers. Their researches have shown that these geyser actions are due to the influence of pressure on the boiling point of water. At normal atmospheric pressure water boils at 100° C but the increase in pressure raises the boiling point whereas decrease in pressures lowers the boiling point of water and the pressure again varies with depth.

At a particular depth the water may reach the boiling point. If the geyser pipe be straight and wide, then convection current will produce a nearly uniforn temperature and boiling springs will result but if the geyser pipe be zigzag and narrow, convection current is effective only for short lengths of the pipe and hence any uniformity of the temperature of water is not possible. At the bends or at the narrow parts of the pipe steam will collect and when the steam pressure has become considerable a quantity of water above gushes out of the pipe. The pressure is thus relieved and there will be no ejection of water unless and until the steam pressure becomes considerable again. This explains the periodic action of geysers.

Two more structures will be discussed here which, though apparently suggest volcanic origin, have however no connection with volcanic activity. They are meteor crater and mud volcano.

Meteor crater—This looks like an explosion pit at the first sight. Closer examination however reveals no supply pipe and hence betrays its non-volcanic origin. Such a depression is the result of a fall of a big piece of meteoritic stone. The collision of the meteor with the ground produces the depression which now resembles an explosion pit in outward appearance. Generally meteoritic matter is found round this depression. Such a depression is called a meteor crater. As for example the meteor crater of Arizona of the United States of America which is 5000 ft. deep.

Mud volcano—This is a conical structure made up of mud resembling very closely a typical volcano in outward appearance. They occur specially in the petroleum field regions, in Russia, in East Indies, in Arakan Coast, in Minbu and Prome areas and Ramri and Cheduba Islands of Burma and in Mekran Coast of Baluchistan. They rise generally to a height of 30 to 40 ft. but in dry climate they rise to greater heights as in Baluchistan the height is sometimes 300 ft. Through the craters mud, saline water, hydrocarbon gases and traces of petroleum come out gently but at times explosion even takes place (PL—31).

Geographical Distribution of Volcanoes—According to Sapper the number of active volcanoes on the surface of the earth is nearly 430, of which 275 are in the northern hemisphere while 155 fall in the southern hemisphere. Of these some are on land but the greater number is in the sea. The number of extinct and dormant volcanoes will be several thousands at rough guess. Several new volcanoes have made their appearance in recent times, such as the Jorullo in Mexico in 1759, the Izalco in Salvador in 1770 etc. The Pacific Ocean is a region of volcanoes. Not only it is encircled by a ring of volcanoes on the coastal region but also it possesses the greatest number of volcanic islands as well as submarine volcanoes. Generally the volcanoes are situated near the sea with the exception of some African volcanoes. The distribution of volcanoes generally follows regions of weakness of the earth's crust and is parallel to some mountain chains and coastal regions. Volcanoes are arranged more or less in several belts. The belt round the Pacific contains the largest number of active volcanoes and is called the *Ring of Fire*. This belt starts from the Cape Horn of South America and passes through the western coast of America, curves round the Aleutian Islands and then passes through the Japanese Island and continues upto the East Indies Islands. Another belt, with a east west direction, starts from the East Indies where it cuts the former belt, passes through Asia Minor, the Mediterranean region and continues upto the West Indies Islands where it again cuts the first belt. Besides these two belts, volcanoes occur irregularly in Antarctica, Iceland and New Zealand.

Indian Volcanoes—Volcanoes are rare in India. The linear extension of the volcanic belt from the East Indies, when produced north westwards, will include two dormant or extinct volcanoes. They are in the Barren Island in the Bay of Bengal (PL—32), and in the Narcondam Island of the Andaman Archipelago. The volcano in the Barren Island was in eruption in 1795 and 1803. It occupies an area of 3 square miles and is 1000 ft. high. It is even now emitting sulphurous vapours. The volcano in the Narcondam Island was active in Pleistocene and since then it has been dormant. There are several other dormant volcanoes in Burma and one Koh-i-Sultan in the Nuski desert in Western Baluchistan which is now in Pakistan.

Classification of Volcanic Eruptions :

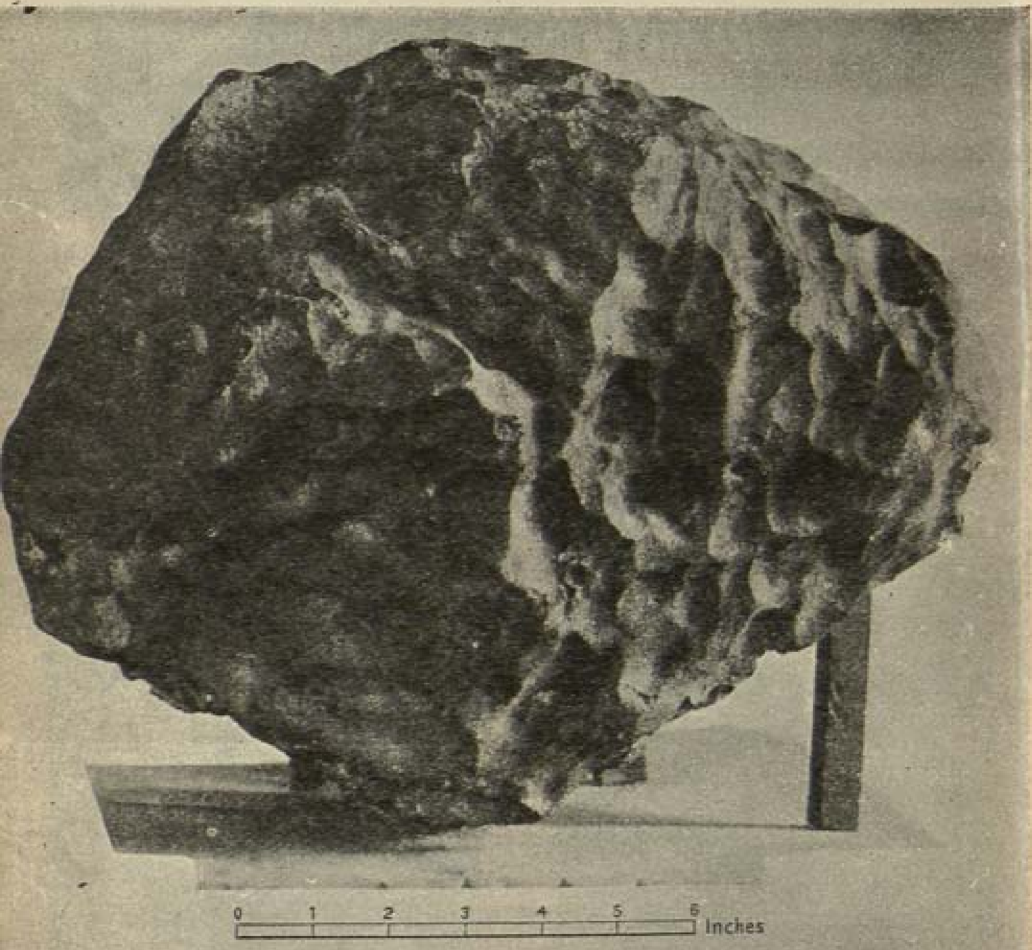
According to the nature and position of the supplying

Pl.—33 Seismogram, Alipore (Calcutta) Observatory.
(By courtesy, Director, G.S.I.)

Pl.—34
Effect of Earthquake
(North Bihar Earthquake, Jan. 15, 1934)
A fissure produced at Sitamari.

Pl.—35
Effect of Earthquake
(North Bihar Earthquake, Jan. 15, 1934)
Distortions of railway lines, Sitamari

(By courtesy, Director, G.S.I.)



Pl.—36 The Merua Meteorite
(By courtesy, Director, G.S I.)

pipe, volcanic eruptions are classified as *central* eruption and *fissure or mass* eruption. This has been already stated.

Depending upon the nature of activity, eruptions are classified as *explosive*, *intermediate* and *quiet*. In an explosive type, the eruption takes place with violent escape of gases and consequent blowing up of the surrounding rock and the production of a huge quantity of fragmental products.

In an intermediate type, the eruption starts with an explosion when a huge quantity of fragmental products are given out and at a later period the explosive action dies down and lava is poured out quietly.

In a quiet type, the eruption only discharges a huge quantity of lava quietly without any explosion.

Eruptions are also classified according to the nature of a particular volcanic eruption for which the names of certain well known volcanoes of the world have been used. They are (from the mildest to the most violent type)—

(1) *Howaiian type*—This is characterised by the quiet discharge of lava without any explosive violence and is the mildest type of volcanic eruption. The lava erupted is mobile and thin and spreads over great areas. Little drops of lava form thread-like masses being blown by wind. These thread-like masses are called Pele's hair, from the name of Pele, the Howaiian goddess of fire. Gases given out are little in quantity and are also discharged very quietly. This type of eruption is exemplified by Howaiian volcanoes and hence the name.

(2) *Strombolian type*—The volcano Stromboli in the Lipari Islands, north of Sicily, shows this type of eruption. Hence the name. In this type the eruption is periodic. With some cessations eruptions take place. The magma is less fluid and particles of lava are blown up into the air to form bombs and scoriaceous fragments. Incandescent masses of gases are given and hence Stromboli is called the Lighthouse of the Mediterranean. At times violent explosions also take place but they are less frequent.

(3) *Vulcanian type*—Volcano, also in the Lipari Islands, exhibits this type of eruption. Hence the name. In this type the erupted magma is very viscous and clots are formed between consecutive explosions. As a result huge quantity of rock fragments is blown during successive eruptions. The gases rise upwards vertically and assume cauliflower-like forms but they are not incandescent as those in the Strombolian type.

(4) *Vesuvian type*—This type of eruption is exhibited by the famous volcano, the Vesuvius near Naples. In this type of eruptions the magma explodes as a result of high gas content. With the eruptions huge quantities of gases ascend in cauliflower-like forms carrying much fragmental materials specially ash.

(5) *Plinian type*—Pliny, the Younger, in his letters to Tacitus described a violent explosion of the Vesuvius. His letters were so descriptive that the most violent type of Vesuvian eruptions is associated with his name. In this type of eruption the cauliflower-like columns of gases rise vertically to great heights. Huge quantities of fragmental products are given out with little or no discharge of lava.

(6) *Pelean type*—This type of eruption is exhibited by the volcano Mont Pelee in Martinique in West Indies. This is the most violent type of all eruptions. The magma is viscous and hence form a hard cover in the volcanic pipe. Lower magma charged with gases forces its way upwards through the sides of the volcanic cone as an avalanche of molten rock material and gases. The gases are ejected more or less horizontally and are dark in colour. The horizontally ejected clouds of gases and lava flows are called *nuees ardente's* in French language.

The above eruptions are associated with the central type of eruptions. The fissures or mass eruptions are very conspicuously shown in the eruptions of Iceland and hence they are called Icelandic type of eruptions.

Origin of Volcanism—The effect of pressure increases with depth in the earth's interior. The pressure effect keeps the subcrustal regions in a viscous state. Any release of pressure which may be caused by the diastrophic movements will melt the rocks below and thereby pockets of magma will be produced in the subcrustal region. This is one of the reason for the occurrence of volcanic belts near the fold mountain belts of the world and the occurrence of igneous activity accompanying major crustal deformations. The magma when formed, will find its way upwards by the pressure of the overlying rocks through fissures, joints, fault planes or bedding planes in the regions above or by melting and digesting the rocks above.

The origin of volcanism is due to the release of pressure at depth and it can be dealt with the explanation for (i) the origin of magma with its high temperature, (ii) origin of volcanic gases and (iii) the extrusion of magma.

Origin of magma—It is believed that the central types of eruptions drain pockets of magma while the fissure types of eruptions may have some connection with the basaltic layer below the crust. Pockets of magma may be produced by the relaxation of pressure locally. Accumulation of radio-actively generated heat may also produce pockets of magma by the melting of rocks. This will also account for the heat. The heat may also come from the hot interior, as it is the common experience that the temperature increases with depth. This heat is in a sense original, being the part left after so many million years of radiation.

It has been observed that a volcano may erupt different types of lavas at different periods and again different volcanoes erupt different types of magmas. These phenomena may be due to magmatic differentiation and assimilation that may take place in a magmatic pocket or in a greater reservoir below supplying different volcanoes.

Origin of volcanic gases—Steam, the most important of the volcanic gases, may result from the descending surface water through the upper part of a volcanic cone. This steam may have a magmatic origin as well. Some amount may be formed by the union of hydrogen of the magma with oxygen or more probably an oxide.

Carbon dioxide may be produced by the heating effects of magma in a limestone region.

Of the other gases like nitrogen, sulphur dioxide (formed from the combustion of sulphur or a sulphide of the magma), hydrogen sulphide, hydrogen, sulphur, chlorine, ammonium and sodium chlorides, carbon monoxide, hydrocarbon gases, boric acid vapour, arsenic vapour, and compounds, phosphorous gases, boron compounds fluorine etc. some are original constituents, some are produced from the reaction of the gases amongst themselves or with the rocks through which they pass and some may also come from the subsurface and descending waters.

Extrusion of magma—Crustal deformation may produce magma on the one hand and on the other it may produce folding and faulting in the upper region and this will lead to the formation of numerous cracks, joints and fissures in the overlying region. These fissures serve as the paths of ascension of the magma. Magma is forced through these cracks by the weight of the overlying rocks. The imprisoned gases are also contributing factors to this point. The energy of the gases will take the magma upon the surface just as water is forced up when a soda water bottle is uncorked.

CHAPTER XV

EARTHQUAKES

An earthquake is a jerking motion in the rocky shell of the earth's crust. As a bell is set into vibration by a blow to its surface or as a pond of water generates waves in all direction when struck by a stone, so also the earth's crust, which has considerable elasticity, is set into tremors by a sudden blow from external and internal causes. The shock produced is sometimes highly disastrous to human life and property. The devastating effects produced by earthquakes can be well perceived from the result of the following well known earthquakes.

(1) The Lisbon earthquake (in Portugal) Nov. 1. 1795 by which 30,000 to 60,000 persons were killed. Most of the city of Lisbon was destroyed. So much loss of life and property was due to the tidal waves produced.

(2) The Naples earthquake (in Italy) in 1857 by which 12,000 persons died.

(3) The Mino-Owari earthquake (in Japan) in 1801 by which the two cities were destroyed and nearly 7,000 persons were killed and 17,000 persons were injured.

(4) The Shillong earthquake (in Assam) on June 12, 1897 by which there was great loss of life and property.

(5) The San Francisco earthquake (in California) in 1906 by which 700 persons were killed and 200,000 persons were rendered homeless.

(6) The Sicily earthquake (in Italy) in 1908 in which 76,000 persons were killed and nearly 100.000 persons injured. Most of the town Messina was destroyed.

(7) The Central Indian earthquake in 1915 by which 30,000 persons were killed and 370 villages and towns were destroyed.

(8) The North and Central Italian earthquake in 1920 by which there was a great loss of life and property.

(9) The Mexican earthquake by which 3,000 persons were killed.

(10) The Tokyo and Yokohama earthquake on September 1, 1923, by which 140,000 lives were lost and enormous damage was done. Practically the whole of Tokyo was destroyed. This is the most devastating earthquake ever known.

(11) The Kansu earthquake (in China) in 1923, when the loss of life was more than 100,000.

(12) The North Bihar earthquake on January 15, 1934 when the loss of life was more than 12,000.

(13) The Quetta earthquake (in Baluchistan) on March 31, 1935, when the loss was more than 60,000.

According to Mallet the earth has lost at least 13,000,000 lives by earthquakes in the past 4,000 years. Fortunately for for us all earthquakes are not devastating and there are many earthquakes which are mere shocks and produce practically no damage. According to Prof. Jones, Japan experiences three shocks per day on the average. It is the land of the rising sun and is also the land of earthquakes.

The science of earthquakes is called *Seismology* which has come from the Greek words *seismos* meaning an earthquake and *logos* meaning science.

Causes of Earthquakes—Earthquakes are, as already stated, jerking movements in the earth caused by a sudden blow. The sudden blow is therefore the immediate cause of the earthquake phenomenon. The jerking movement may be on the other hand, due to exterior as well as interior causes.

Aristotle believed that underground air in its endeavour to come out shakes the earth. Lucretious believed that the collapse of underground ·caves produced shocks. Magnati in 1688 A.D. proposed the action of wind, water and heat, and the concentration of coaly matter for the cause of earthquakes. It is due to the researches of Mallet, Milne, Reid, Imamura, Omori and others that we have at present a fair knowledge of the science of earthquakes though there are many things yet to be made elear.

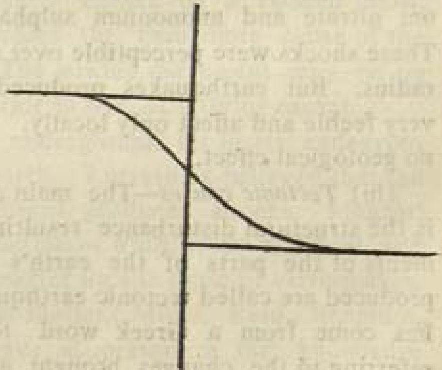
The causes of earthquakes may be divided into three groups—(i) surface causes (ii) volcanic causes and (iii) tectonic causes.

(i) *Surface causes*—Earthquakes may be generated by landslides in mountainous regions. The Turkestan earthquake on February 13, 1911 was believed to be due to a huge landslide in the Pamir region when 500,000 million tons of rock fragments slipped through a length of nearly 2,000 ft. But Oldham has shown that landslides are more often the effect than the cause. Slips on steep coasts, avalanches, underground roof callapse may also produce earthquakes. Differential movements of the parts of the earth along the equator and other places, variations of temperature, variation in the weight of the atmosphere, variation in the distribution of snow and water and the dashing of the sea waves against the coast may also be cited as minor causes producing slight tremors. Slight tremors are often recorded in the Alipore observatory (Calcutta) which are caused by the dashing of sea waves against the Coromandel Coast.

(ii) *Volcanic causes*—Volcanic eruptions can produce earthquakes. Thus the explosion at Krakatoa in Sumatra in 1888, Ischia in the Bay of Naples in 1883 and Bandaisan in Japan in 1888 produced earthquakes. Similarly earthquakes were produced artificially by an explosion of 4500 tons of ammonium nitrate and ammonium sulphate at Oppau in Bavaria. These shocks were perceptible over an area of 300 miles as the radius. But earthquakes produced by volcanic eruptions are very feeble and affect only locally. They produce practically no geological effect.

(iii) *Tectonic causes*—The main cause of the earthquakes is the structural disturbance resulting in the relative displacements of the parts of the earth's crust. Earthquakes thus produced are called tectonic earthquakes. The word tectonic has come from a Greek word *tekton* meaning a builder, referring to the changes brought about in the earth's crust. Most of the disastrous earthquakes are of this kind and occur in places near great fractures. Such earthquakes generally result from sudden yielding to strain produced on the rocks by accumulating stresses. This causes the breaking of rocks and produces relative displacements of rocks. Such faulting causes shaking because displacements of rocks can only be possible by overcoming frictional resistance against the walls of the fault plane. The association of earthquakes with fault lines is an established fact. Generally speaking earthquakes occur in old fault zones. They may also be the result of new ones. Earthquake-shaken areas often bear conspicuous signs of faulting such as displacement of ground in vertical, horizontal and inclined directions. It must be remembered that every earthquake does not produce any visible sign on the surface. Commonly the displacement is too deep to leave any sign on the surface. One example of such earthquake is San Francisco earthquake in California in 1906. This earthquake was the result of a displacement along a great 600 miles long fault zone known as the San Andreas Fault. Horizontal displacement of surface rocks are clearly visible on the surface. The earlier shocks of 1868 and 1872 of this area are also referable to this fault.

Prof. H.F. Reid after a careful study of the San Francisco earthquake of 1906 and of the San Andreas Fault has proposed a new idea for the origin of earthquakes which is the *elastic rebound hypothesis.* According to him stresses on the two sides of the fault plane were accumulating and produced bending of rocks. When the rocks could bear no more straining, breaking with sudden displacement of the elastic rocks on the two side of the fault took place producing a blow to the upper rocks on one side of the fault-plane and to the lower rocks on the other side as shown in the figure.



Fig—55
Elastic rebound

In Assam earthquake (1897) a vertical displacement of 35 ft. in places occurred along the Chidrang Fault running for a length of nearly 12 miles in NNW-SSE direction. Tilting was also noticed in a tract in Cutch as a result of an earthquake occurring on June 16, 1819.

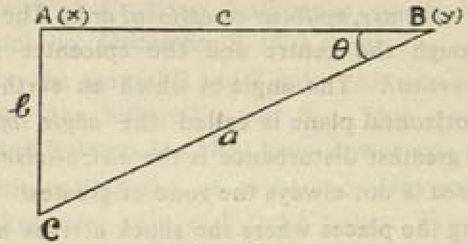
Submarine Earthquakes—Earthquakes often occur under the sea water on the beds of the seas. Such earthquakes can not spread very far in water. They are only to be perceived by a passing ship and can be recorded by seismographs. But their effects on the sea waves are considerable. Vertical displacement on the sea bottom causes huge sea waves known as *tsunamis* in Japanese language, which produce devastating effects on the sea coasts. In open oceans their heights are scarcely preceptible but in length they are 100 to 200 miles and in speed they range from 300 to 500 miles per hour. Such tsunamis often damage the Japanese coast, as in 1703 and 1896. The Lisbon earthquake in 1755 which originated from a submarine displacement caused a great tsunami as high as 40 ft.

Classification of tectonic earthquakes—Tectonic earthquakes may be classified according to the depth of origin.

(1) *Earthquakes of normal or shallow depth*—When the origin is at a depth of 0 to 30 miles.

(2) *Earthquakes of intermediate depth*—When the origin is at a depth of 30 to 150 miles.

(3) *Deep earthquakes*—When the origin is at a depth of 150 to 450 miles.



Fig—56
Determination of the depth of an earthquake

Depth of origin—The depth of origin of an earthquake can be determined in the following manner according to Oldham

Intensity of the earthquake A=X (determinable).

Intensity of the earthquake at B=Y (determinable).

Distance between A and B=C (determinable).

By the inverse square law (i.e. the intensity varies inversely as the square of the distance)

$$\frac{y}{x} = \frac{b^2}{a^2} = \sin^2 \theta$$

∴ The angle θ can be determined.

∴ Depth of origin = b = AC = c tan θ.

There is a conflict of opinion among the seismologists as to the depth of origin of earthquakes. Some say the origin is very deep, others hold they are shallow in origin. It is probable that the origin of tectonic earthquakes is generally deepseated, more than 100 miles deep from the surface. These can produce effects over wide areas whereas volcanic ones are quite shallow in origin. Thus G.W. Walker puts the origin of the Pulkova (near Leningrad) earthquake at 800 miles nearly. R. D. Oldham puts the origin of the the Assam earthquake of 1897 to a depth between 100 to 200 miles. Prof. H. H. Turner holds that majority of earthquakes are deep-seated in origin, more than 100 miles, to which the Japanese seismologist K. Wadati agrees.

Mode of Propagation—The place from which an earthquake starts is known as the *focus, origin, hypocentre or centrum*. It should be remembered that the focus is not a point but is often a lengthy tract. The area vertically on the surface over the focus is called the *epicentre, epifocus or epifocal area*. The vertical line passing through the centre and the epicentre is known as the *seismic vertical*. The angle at which an earthquake wave meets the horizontal plane is called the *angle of emergence*. The area of greatest disturbance is the *meizo-seismic* area. The epicentral area is not always the zone of greatest disturbance. Lines joining the places where the shock arrives at the same time are called *homoseists or homoseismals or coseismals* and lines joining places where earthquake is of equal intensity is known as *isoseists or isoseismals*. If the focus be at a point, the coseismals will be circles, but as the focus is a tract rather than a point, the coseismals are generally elliptical.

From a study of the distribution of homoseismals and isoseismals the epicentre can be determined. Sometimes the focus may be along several parallel, radial or intersecting lines.

The main shock of earthquakes is preceded by preliminary tremors. These are again divided into two groups— (1) *Primary*, *Push* or P-*waves* which are longitudinal and compressional in nature and are similar to those of sound waves in which the movement is to and fro in the lines of propagation, and (2) *Secondary*, *Shake* or S-*waves* which are transverse and distortional in nature and are similar to those of light waves in which the movement is at right angles to the lines of propagation. These preliminary waves are followed by the main shock. The main shocks travel near the surface region whereas the P and S waves can pass through solids. (3) The main waves are called the *Free*, *Long* or L-waves. They are also known as the *ground* waves or the *Raleigh* waves. The L waves follow a circumferential path whereas the P and S waves proceed towards the centre. The peculiarity of the P and S waves is that they are subject to optical laws of reflection and refraction. If the earth would have been homogeneous, the P and S waves would have been straight lines. Gradual increase in density with depth will cause a concave path for the P and S waves. After the main waves have died down (4) *after shocks* are felt (PL—33.)

The record of Croatian earthquake (in the Kulpa Valley in Jugoslavia) on December 8, 1902 shows two other P and S waves besides the normal P and S pair. This new pair has been designated by the letters Pg and Sg. They are similar to ordinary P and S waves but they have slower rate of travel.

The Tauern earthquake of Austria on November 23, 1923 shows another new pair of P and S waves. These have been designated as P* and S* waves in seismological literature. They are also similar in nature to ordinary P and S waves but have intermediate velocity between P-S and Pg-Sg pairs. At a distance of 500 miles from the surface all the pairs travel with equal velocity.

The facts are best explained by the assumption that there are three distinct layers in the outer region of the earth. The ordinary P and S waves have travelled through the lowest layer which is believed to be consisting of dunite or peridotite rock material. The P* and S* waves have travelled through the intermediate layer, believed to be formed of basaltic or amphibolitic material, whereas the Pg and Sg waves have travelled through the outermost layer belived to be granitic in composition. These have been dealt in the chapter on the Interior of the Earth (Chapter—XVI).

The P-waves are the fastest and then come the S-waves and the L-waves last of all. The P-waves can be transmitted through solids as well as fluids but the S waves are obstructed by fluids. The L-waves are believed to be produced by the P and S waves. They produce the greatest damage on the surface.

Intensity of Earthquakes—The conception of isoseismal lines demands a scale of reference to measure the intensity of earthquake waves at different places on the earth's surface. The intensity is measured by the effect of an earthquake on a seismograph, by the sensation of people and by the damage to buildings and ground. The first one to be introduced is that by an Italian seismologist Rossi and Forel, a Professor at Geneva. It has got ten divisions as shown on the next page.

Intensity	Name of the shock	Effects
I.	*Microseismic*	Recorded by delicate instruments only.
II.	*Extremely Feeble*	Recorded by all seismographs. Felt by experienced persons only.
III.	*Very Feeble*	Felt by several persons at rest.
IV.	*Feeble*	Felt by persons in motion. Affects windows and ceilings of houses.
V.	*Moderate*	Felt by every one. Greater disturbance on houses and produces ringing of bells.
VI.	*Fairly Strong*	General awakening of persons from sleep and ringing of bells. Clocks stop. Trees oscillate.
VII.	*Strong*	Overthrows movable objects. Causes removal of plasters but no general damage to building. Church bell rings.
VIII.	*Very Strong*	Fall of chimneys and cracks in the walls of buildings.
IX	*Extremely Strong*	Partial or complete destruction of buildings.
X.	*Shock of Extreme Intensity*	General destruction of buildings and ground. Produces landslides in mountainous regions.

Mercalli, an Italian seismologist, put forward another scale. It had at first ten divisions but later the number of divisions was made twelve. This is as follows. (The acceleration produced measures the intensity of vibration. The acceleration due to gravity in this scale would be 980 cm/sec/sec).

Intensity	*Acceleration produced*	*Name of the Shock*	*Effects*
I.	Less than 1 cm/sec/sec	*Instrumental*	Recorded by seismographs only.
II.	Over 1 cm/sec/sec	*Very Feeble*	Perceived only by sensitive persons.
III.	Over 2·5 cm/sec/sec	*Feeble*	Perceived by persons at rest.
IV.	Over 5 cm/sec/sec	*Moderate*	Perceived by persons in motion.
V.	Over 10 cm/sec/sec	*Fairly Strong*	Wakes persons. Rings bells.
VI.	Over 25 cm/sec/sec	*Strong*	Slight damage to buildings.
VII.	Over 50 cm/sec/sec	*Very Strong*	Produces cracks in the walls.
VIII.	Over 100 cm/sec/sec	*Destructive*	Throws chimneys.
IX.	Over 250 cm/sec/sec	*Ruinous*	Overthrows buildings.
X.	Over 500 cm/sec/sec	*Disastrous*	General destruction of buildings.
XI.	Over 750 cm/sec/sec	*Extremely Disastrous*	Few buildings are left standing. Causes fissures in the ground.
XII.	Over 980 cm/sec/sec	*Catastrophic*	Total destruction of buildings and ground. Objects thrown up.

Earthquake Recording Instruments or Seismographs—Primitive and crude methods for ascertaining the directions of earthquake waves were made from the wave directions of water, specially of coloured water. Later troughs full of mercury with grooves connected to tubes were devised, from which earthquake would overthrow mercury through the grooves into the tubes and from an observation of this the direction would by determined. Chand Heng of China, devised a method in 132 A.D. to record the earthquakes. This was the first of its kind. It had the figure of a frog at the centre of a vessel which was again surrounded by eight figures of dragons sitting on spring and each holding a ball in its mouth. When there was an earthquake the nearest dragon would throw the ball into the mouth of the frog and thus the direction of the earthquake waves would be determined. In more recent times the pendulum seismographs came into existence. It consists of a horizontal pendulum which records the earthquakes by means of a beam of light thrown on a piece of photographic paper by the reflecting mirror attached to the pendulum. The time is measured by dots at the end of each minute.

Seismograph or the distant earthquake recording instrument, in its present day form, consists of a stout pillar attached firmly to the floor of the observatory building. *Seismometers* record local shocks only. The pillar of the seismograph is connected by means of a wire to a cylindrical rod with a sharp point at its upper end. The sharp end moves between two bifurcations of a long pointer having a pencil point at the other end. The pencil point touches a rotating drum with paper fixed on its upper surface. When there is an earthquake the building is shaken and so the pillar is also shaken. Its pointed end therefore alternately strikes the bifurcated parts of the long pointer. The pencil point attached to the other end of the pointer record the oscillatory movement on the paper over the drum.

In later forms of seismographs instead of pencil point there is a mirror arrangement which throws a ray of light on the photographic paper on the rotating drum. The paper, on development, will show the record of the earthquake shocks. A chronograph, attached to the instrument, records the time of arrival of the shock.

The record left on the paper (ordinary or sensitised as the case may be) is known as the *seismogram.*

Earthquake belts or Seismic belts—Upon the surface of the earth there are a few more or less well defined areas where earthquakes are more frequent than in other areas. These areas are called *seismic belts.* One such seismic belt encircles the Pacific Ocean and is known as the Circum-Pacific belt. This is the most violently shaken area where 68 p.c. of the earthquakes occur. The other is the Mediterranean seismic belt which starts from the East Indies and passes through the Himalayan foot-hill region, Asia Minor and the Alps. Here only 21 p.c. originate. The rest 11 p.c. originate else-where. Roughly the seismic belts coincide with the volcanic belts of the world and more closely with the young mountain belts of the world. The rift valley region of the East and Central Africa is another minor seismic belt. Earthquakes are rare in the Atlantic region and in the interior of Europe including Britain but it should be remembered that no area is totally free from earthquakes.

Earthquakes are especially frequent where slope is steep specially on the outer side of a mountain or in steep coastal regions. Crustal disturbances produce such steep slopes and as crustal disturbances are also the cause of earthquakes, the seismic belts lie in areas with steep slopes.

Indian Earthquakes—(1) *The Assam Earthquake*—This is one of the most disastrous shock that has occurred ever on the surface of the earth. The research of R. D. Oldham (Mem. G.S.I. Vol. XXIX, 1899) has made it well known to the scientific world. This earthquake occurred on June 12, 1897. Rumbling sounds were heard two seconds earlier. The surface moved backward and forward like trees caught in a storm. Shillong and neighbouring areas of 150,000 square miles were almost destroyed within a minute.

The main shock lasted for one minute but the damage was done in first half of it. Fissures developed on the ground and through these fissures water overflowed and land slides occurred in huge quantity. The drainage system of the area was highly disturbed.

The earthquake originated from a fault zone more or less parallel to the Chidrang River. The horizontal vibration attained an amplitude of 7 inches and the velocity of the waves was according to Oldham 2 miles per sec. nearly. The ground vibrated more than 200 times a minute.

On August 15, 1950, at about 7-40 P.M. Assam, particularly the north-eastern part of it was rocked by another tectonic earthquake of great intensity. At Shillong, three shocks were felt. The first lasted for five minutes, the second and the third for one minute each. Seismographs at Calcutta and Poona were thrown out of order. It was more severe than the North Bihar and Baluchistan (Quetta) earthquakes. The epicentre was located at latitude 29°N and longitude 97°E, near the Lohit River. The shock devasted an aera of 5000 sq. miles (excluding the northern hilly region). Dibrugarh, North Lakhimpur, Sibsagar, Jorhat, Pasighat and Tinsukia were affected severely. Railway lines were dislocated, bridges (as the Ranganadi bridge) damaged and roads fissured. Landslides blocking river courses (as in the cases of Subansiri, Lohit etc.) occurred resulting, at a later period floods by the removal of the rock debris.

(2) *The North Bihar Earthquake*—It occurred on Jan. 15, 1934 at about 3 P. M. The northern part of Bihar and Southern Nepal were shaken by a severe earthquake. The worst affected areas were Motihari, Katmundu and Monghyr. Numerous cracks were developed and water overflowed through these. More than 12,000 people were killed. The cause is believed to be due to some displacement below the alluvial plain at Motihari area. It has not produced so much geological effects as the Assam earthquake though it is highly destructive to human life (Vide Record, G.S.I. Vol. LXVIII, Pt. 2).

(3) *The Quetta (in Pakistan) Earthquake*—This occurred on May 31, 1935, at night when nearly 20,000 persons were killed. The worst affected area was very small compared to the destruction and hence it is believed that the origin was shallow. The epicentral area was between Quetta and Kalat. It was only 68 miles in length and 16 miles in breadth. Cracks were numerous on the ground and so also the rock falls but other effects were not so much pronounced (Vide Dr. West's report in the Rec. G.S.I. Vol. LXIX—Pt. 2.)

The study of Indian earthquakes shows that in the Himalayan region, where the younger rocks come in contact with the older rocks, earthquakes are frequent. These areas are naturally very unstable and displacements are often caused to relieve the strain. In the syntaxial bends disastrous earthquakes have occurred. The valley floor of the Indo-Gangetic Plain may also be at times displaced owing to the superincumbent load of sediments. The North Bihar Earthquake in 1934 supports the idea.

Geological Effects of Earthquakes—Apart from the immediate destruction of life and property, earthquakes produce other geological effects. Due to the passage of surface waves fissures are produced and through these fissures water often overfloods the region. This water brings enormous quantity of sand and often produces sand-dikes in these fissures. Roads are fissured, railways are twisted, submarine cables are damaged and bridges fall off from the pillars. A marked change is effected on the drainage system of the area. Rivers change their courses. New springs appear. Old springs stop. sometimes discharge of springs is increased and sometimes it decreases. Rock slides occur in hilly region and bring down huge quantity of rock material and thus aid the mass wasting process. Grounds are tilted and changes of ground level are at times effected. Relative displacements of areas and increase in the height of hills are also at times effected by earthquakes.

Prevision of Earthquakes—Earthquakes cannot be prevented but their forecast, like weather forecast, can be of immense value in minimising the disastrous effects by keeping people alert against the consequences of subsequent earthquakes. Earthquakes generally occur all on a sudden and without any warning. Sometimes preliminary tremors or rumbling sounds are perceptible but these are very rare.

As already pointed out the cause of the earthquake is the relief of strain by the displacement of the strata. When the strain is accumulating, some effects like slight tilting of ground or small rockslides are often seen.

Prof. Reid suggests the construction of a number of piers at some distances perpendicular to visible or supposed direction of a fault and a careful and regular study of them is likely to give some idea of the accumulating strain which is to cause an earthquake at a later date.

The second method is due to Dr. Davison. He suggests the recording of shocks and the increase in seismic activity along a known fault zone.

Late Prof. H. C. Das Gupta suggested a careful study of rain and snow fall. In humid countries rain water and snow are the main transporting agents. Again great stresses are set up by the transfer of materials from one place to another according to the ideas of isostatic adjustment. Therefore there is a likelihood of existence of a relationship between the rain and snowfall on the one hand and the periodicity of earthquakes on the other. Prof. Knot also believed in the same way and the Japanese seismologist Prof. Omori had shown that there is a coincidence between the rain and snow fall, and earthquake frequency. The idea however stands on a debatable assumption that earthquakes are of shallow origin.

Construction of Buildings in Earthquake Areas—Near the epicentral area the damage is at its maximum. Fortunately the area has a small dimension generally. Outside this area a careful design and a scientific choice of building materials may save many a building from collapse. From the ancient time man has been thinking of this problem. The temple of

Diana at Ephesus near Smyrna, off Greece, was built on a marshy land to protect it from any damage by earthquakes.

The surface waves are the most destructive. The damage depends upon the rate of vibration of earthquakes and the oscillation period of buildings.

To bear the strain two opposite methods in construction have been followed. In one, the idea is to make the structure very light and thus make it able to absorb the shock. In another the idea is to make the structure very firm so that the shock can have no effect on the building. The foundation upon which a building stands has been made loose or firm according to the two different ideas. The former method has rather been proved to be unsuccessful. A loose foundation can absorb the vibration to some extent but the surface waves here are higher whereas in a firm foundation the vibration is greater but the surface waves are lower in amplitude.

Windows and doors make the walls less strong. Vertical rows of them are worse than diagonal rows. Low buildings can bear damage from errthquakes more than high ones and it is better to have a square foundation.

Of the building materials, a steel frame with reinforced concrete is the best and ordinary bricks are the worst as earthquake-resisting material.

CHAPTER XVI

INTERIOR OF THE EARTH

The interior of the earth is not approachable for direct observation. It has been possible for man to go 1·7 miles only inside the earth by digging and the deepest well that has been sunk for petroleum has gone not more than 3·9 miles inside the earth. Some of the shafts of the Kolar gold mines in Mysore have reached depths of more than 9000 ft. and are believed to be the deepest in the world. The deepest pipe for petroleum has reached a depth of 20,521 ft. in Wyoming.

These depths are so insignificant in comparison to the radius of the earth (which is nearly 4,000 miles) that no precise knowledge can be got from these diggings and borings. Scientists adopt indirect methods to get an idea of the interior of the earth.

Internal Heat—That the interior of the earth is intensely hot goes without saying. The more one goes down inside a mine, the more one experiences the gradual increase of temperature inside· Besides these, the internal heat is discernible from the many hot springs and volcanic eruptions in different parts of the earth. It has been noticed that for every 100 ft. of descent there is a rise of 1°C in temperature downwards from which the central heat comes to be 20,000°C nearly. But because of the relatively high concentration of radioactive elements near the crustal region, the temperature gradient or the rate of rise of temperature is probably higher in the upper part of the crust than it is downwards. It is believed that the core of the earth may have a temperature of nearly 6,000°C. This is the same as the temperature of the outer part of the solar disc out of which the earth originated.

Like temperature, pressure is also tremendous at the central part of the earth. It has been observed that at a depth of 1 mile, the pressure is 450 tons per square foot of area. From that it has been calculated that the core of the earth will receive a pressure of 2 million tons per square foot. As the value of the acceleration due to gravity decreases with depth, the value of the interior pressure is likely to be much less. Heat increases the volume of a substance, pressure diminishes it. Inside the earth these two opposite agents are working. Owing to the tremendous pressure and heat, materials inside the earth are likely to be pliable but it is not thought to be liquid.

Many places upon the surface of the earth are covered by sedimentary rocks. Below that there are igneous rocks, the sp. gr. of which varies from 2·75 to 3·1. But the density of the earth as a whole is 5·5. From this it it clear that the internal material of the earth must be very heavy with a sp. gr. as high as 7 or 8. Mere pressure cannot increase the sp. gr. to such an extent. Hence it is thought that the interior of the earth is made up of some heavy metallic elements. The meteorites are generally made up of nickel and iron compounds. They are also members of the same solar system. Hence from their composition it can be guessed that the interior of the earth is made up of nickel and iron. The response of the earth to magnetic forces also bears testimony to this idea as nickel and iron are two of the most highly magnetic substances.

The earth first assumed a liquid state and then it passed into the solid state. According to many, the earth is solid only on its upper surface, the interior is molten. They cite volcanic eruptions as evidence. The failure of the earth to respond to the attractive forces of the sun and the moon to produce tides upon the surface, discards the idea. Others hold that the crust and the centre are solid and the intervening part is liquid. Some others think the intermediate part between the centre and the crust to be gaseous. Definite opinion on this subject requires precise observation of the effect of pressure and heat in the interior of the earth. Direct observations being impossible, help of indirect methods is generally sought for.

Now-a-days a fair idea of the interior of the earth has been obtained from the study of the propagation of seismic waves through the earth. Originating from a volcanic eruption or more probably from an underground dislocation of rocks, an earthquake starts in the form of waves in all directions just as a surface of water disturbed by a stone, produces waves starting from the place where the stone falls on the surface of water. These waves are recorded by seismographs.

Generally speaking there are three types of earthquake waves—the P, S and L waves. Of these the normal P and S waves can pass through solids. The L-waves pass through the circumferential area of solids. From the study of earthquakes of different areas, two more sets of P and S waves have been detected. Of these two sets one set has a velocity less than that of normal P-S set. The velocity of the other is intermediate between that of this set and the normal set (Chapter XV—Earthquakes).

Three layers with different density have been thought out to account for the three sets of P and S waves. It has been thought that the slowest P—S set has gone through the outer layer of the lightest material; the one with intermediate velocity has gone through the intermediate layer with intermediate density and the normal P-S—set has gone through the lower layer of still heavier material. These layers are made up of progressively denser materials.

Lower layers are compressed by the pressure of the superincumbent layers and hence the material composing the lower layer becomes heavier. It has been conjectured that the three above mentioned layers are composed of granite (upper layer) basalt or basalt glass or amphibolite (intermediate layer) and dunite or peridotite (lower layer) successively. Their successive thickness is believed to be 6, 12 and 18 miles respectively. These three layers constitute the upper silicate layer.

The L-waves while passing through ocean-floors acquire more velocity than while passing through continental land masses. This shows that the material (granite) with which land masses are generally composed is practically absent on the ocean bottom. The L-waves generally take a circumferential path round the earth and hence they cannot tell much about the interior. It is with the help of P and S-waves that a fair idea of the interior of the earth can be obtained. These waves behave like light waves and as the light waves are reflected and refracted by lenses, so these P and S-waves are reflected and refracted. The areas of heavier rocks act like lenses in the latter case.

The velocity of P and S-waves goes on increasing up to a depth of 1800 miles. Pressure effect is the cause. Below 1800 miles the rate of increment diminishes. Below 600 miles the diminishing is noticeable. From that it is thought that materials below 600 miles are quite different from the materials above it. The centre fails to transmit S-waves and the P-waves become extremely faint. It is therefore believed to be in liquid state but Gutenburg claims to have detected S-waves passing through the centre. The centre is believed to be made up of nickel and iron and is therefore called *nife*.

The following is an arrangement of the layers of the interior of the earth. This is according to Vander Gracht, Gutenburg and others.

(1) *Outer silicate layer*—This layer contains compounds of the elements O, Si, Al, K, Na and a little of Fe and Mg. Density 2·75—3·1. Thickness 36 miles. This layer is again sub-divided into three sub-layers.

(a) *Outer sub-layer*—It consists of granitic type of rocks. Density 2·75 nearly. Thickness 6 miles nearly.

(b) *Intermediate sub-layer*—It consists of basaltic or amphibolitic type of rocks. Density 2·9. Thickness—12 miles nearly.

(c) *Inner sub-layer*—It consists of dunite or peridotite type of rocks. Density 3·1. Thickness 18 miles.

(2) *Inner silicate layer*—This layer contains compounds of O, Si, Mg, Fe and Ca, K and Na rare. Density 3·10 to 4·75. Thickness—700 miles nearly.

(3) *Pallasite layer*—(Pallasite is a compound of Ni and Fe)—This layer contains compounds of O, Si, Mg, Fe, and metallic Ni and Fe. Ca, Al, K and Na are absent. Density from 4·75 to 5·0. Thickness—1100 miles nearly.

(5) *Core or Nife*—It consists of metallic Ni and Fe. Density 11·0. Thickness 2200 miles.

V.M. Goldsmidt from an analogy with the extraction of Fe and Cu has depicted the interior of the earth in a slightly different way. During the extraction of Iron and Copper from their ores, a layer of oxide and sulphide forms above the metallic layer. Goldsmidt likewise conceived such an oxide and sulphide layer above the metallic Ni and Fe core. According to Goldsmidt the layers are arranged as below.

(1) *Outer layer*—Density 2·8. Thickness 75 miles nearly.

(2) *Eclogite layer*—Density 3·6 to 4·0. Thickness 650 miles nearly.

(3) *Oxide-Sulphide layer*—Density 5 to 6. Thickness 1100 miles nearly.

(4) *Core*—Density 8 to 11.5. Thickness–2200 miles nearly.

Thus inside the earth there seems to be a density stratification i.e. arrangement of materials according to density, the heavier being at greater depth. If we remember that the earth passed into the liquid state from the gaseous state and to the solid state from the liquid state this seems to be quite in keeping with our expectation.

Crust—It is the outer part of the earth which possesses high strength and rigidity. It is also called the *lithosphere*. Below the crust lies the substratum which is very weak and vitreous.

Sial—The upper most sub-layer in the crust of the earth is called the sial (from silicon and aluminium). It contains the lightest materials (granitic) of density 2·75 nearly. Na, K, Al, Si and O with a little of Mg and Fe are present in it.

Sima—Below the sial layer comes the layer of sima named from silicon and magnesium. It contains basaltic, amphibolitic, dunitic or peridotitic materials which are quite heavy. Density varies from 2.9 to 3.1.

The three sub-layers in the outer silicate layer, already referred to, can be arranged thus :

Sial—	Upper sub-layer	Crust
Sima—	Intermediate sub-layer	
	Lower sub-layer	Substratum

Nife—The core or the central part of the earth which is believed to contain metallic nickel and iron (ferrum) is called nife. Density of the nife is 8 to 11·5.

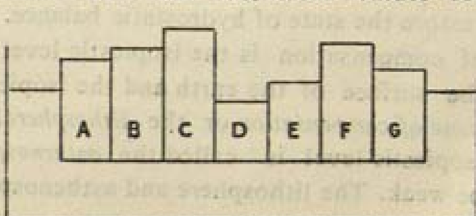
CHAPTER XVII

SOME WORKING HYPOTHESES

1 Isostasy—The word Isostasy has come from the Greek word *Isostasios* meaning "in equipoise". It was first used by the American geologist Dutton in 1889 (though ideas of isostatic adjustment were already thought of) to denote the equilibrium existing between the elevated masses and the depressed basins and a tendency of these elevated masses and the depressed basins to reach a sort of hydrostaic balance. Dutton suggested that the elevated masses are characterised by rocks of low density and the depressed basins are characterised by rocks of higher density. Accordingly a level is thought to exist where the pressure due to the elevated masses and depressed areas would be equal. This is called the *isopiestic level* or the level of uniform pressure. It is imagined that on unit area on this level the pressure due to the overlying masses is the same every where, whatever may be the height of the columns or whatever may be their surface relief. It is clear that higher columns will have low density and lower columns will have high density materials so that the weight of these two columns on the isopiestic level may be the same. Any loading due to sedimentation, deposition of ice and intrusion of igneous matter, or unloading due to denudation and melting of ice, of the columns will therefore disturb the balance and compensation in the form of depression or elevation will follow to restore the state of hydrostatic balance. The maximum depth of compensation is the isopiestic level and the zone between the surface of the earth and the isopiestic level is called the *zone of compensation* or the *lithosphere*. The zone below the isopiestic level is called the *asthenosphere* which is held to be weak. The lithosphere and asthenosphere are equivalent to crust and substratum.

Development of the idea of isostasy has been due much to the work of geodesists who use two important methods of investigation (i) deflection of the pendulum from the true vertical direction at mountain stations due to the attraction of the upstanding masses and (ii) gravity measurement.

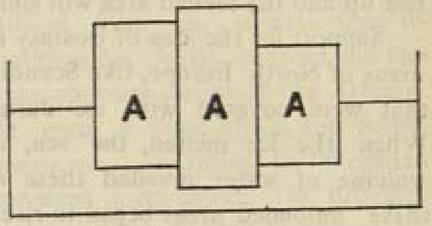
A pendulum bob suspended near an upstanding mass will be attracted laterally towards the mountain and will deflect from the true vertical direction. From the assumption that the average density of the rock on the surface and below the upstanding mass is the same and knowing the volume of the upstanding mass, the lateral attraction can be calculated. This calculated value is then compared with the observed value after reducing both to the surface of an ideal globe. Actually it is found that the deflection of the pendulum bob from the vertical is only a fraction of the calculated value. The difference between the calculated value and observed value, in the case of pendulum deflection, is called the *unexplained residue*. During the survey of the low lands south of the Himalayas the deflection of the pendulum from the true vertical due to the attraction of the visible masses of the Himalayas and Tibet was calculated to be 15″·885 seconds of arc and found to be 5″·328 seconds of arc. The explanation is that the rock below the upstanding masses is light i.e. composed of low density materials or there is a deficiency of mass. This explanation is further supported by gravity measurement. This oscillation of pendulum is governed by the intensity of gravity which varies with altitude, latitude, etc. By considering these factors the value of gravity can be calculated. It is observed that the calculated values for mountain stations are higher than the observed values. The difference between the calculated value and the observed value, in the case of gravity measurement is called *anomaly*. The



Fig—57
Isostatic balance

explanation is the same as before, namely that there is a deficiency of mass in the upstanding columns of mountain masses. Similarly it is thought that there is an excess of mass in the rocks of low lands or depressed basins.

In fig. 57 all the blocks have the same weight and cross-section. Hence they will sink to the same depth in a suitable liquid medium. Their lengths will vary inversely as their densities and the upper surfaces will be irregular. The longer blocks may be taken to represent mountains and lower blocks ocean basins. This figure illustrates the principle of hydrostatic balance.



Fig—58
Isostatic balance

In fig. 58 all the blocks are made up of the same material but they are of different heights. Hence they will sink to different depths in a liquid medium and irregularties will be both on the surface as well as below. Seismological, geophysical and geological considerations point to the possibility of the second kind of arrangement and balance.

If a portion is cut from any block in any figure and placed on the other, equilibrium is disturbed and restoration of equilibrium is effected by the rising of the unloaded part and sinking of the loaded part. Causes of loading and unloading have been already stated.

The equilibrium is again restored by the flow of mobile asthenospheric material at depth as a consequence of which the loaded block sink and lighter adjoining blocks rise upwards. Immediate and perfect adjustment is however not possible. This is because of the strength and resistance of the lithosphere and viscosity of the asthenosphere.

When a mountain mass or an elevated plateau is undergoing denudation, the sediments are taken and deposited in an adjacent low-lying tract. Hence with denudation the mountain or the plateau becomes lighter as a result of loss of material and the low-lying tract, where the deposition is going on, becomes heavier as a result of sedimentation. Hence the pre-existing equilibrium between the elevated and depressed areas is disturbed and to restore it the unloaded area will rise up and the loaded area will sink down.

Support for the idea of isostasy is obtained from the rise of areas of North Europe, like Scandinavia, and North America that were covered with ice during Pleistocene glaciation. When the ice melted, the sea, as a result of the increased volume of water invaded these areas. After sometimes these unloaded areas began to rise up and as a result the sea began to recede, proving thereby the principles of isostasy.

2 **Continental Drift**—There are three persons who assume the drifting of sial blocks over the simatic layer as a result of which the present configuratian of the earth with its mountains, continents and oceans was reached. They are Taylor, Wegener and Daly.

Taylor assumed the drifting of the continental blocks towards the equator to explain the formation of the Tertiary mountains. He cites the tidal forces of the sun and the moon as a cause for it. Taylor says that the moon was captured by the earth in late Cretaceous time which increassd the tidal forces from that time. The earlier mountains, he thought, to be result of the attractive forces of the sun when the earth was, in his opinion, nearer the sun. The Middle Carboniferous glaciation however goes against the idea.

Alfred Wegener, another propounder of the drifting of continents, was a German meteorologist. In his research to determine the climates of the past he noticed that there are such places on the surface of the earth where the present climate does not tally with that of the past. There are some places where once there was cold climate but now it is having hot climate. This might have been caused in two ways—either the climate has changed or the position of the place has been altered. To imagine the change of climate it requires the assumption of many changes like that of solar radiation, the inclination of the earth's axis etc., which are not acceptable. So only the change of position of the place is left to explain the change of climate or, in other words, the continental parts have drifted from one climatic zone to another. Similarity in stratification, fossil content and the strike of the mountains on the opposite shores of the Atlantic Ocean suggests that once upon a time Africa and South America formed a single continent. According to Wegener an west-ward and an equator-ward force caused the drifting. The equator-ward force was responsible for the formation of the Alpine-Himalayan chain of mountains and the west-ward force was responsible for the formation of the Rockies and the Andes. As a cause Wegener cited tidal forces for the equator-ward drift and centrifugal force resulting from the difference in altitudes of the centres of gravity of the sial and simatic layers. According to Wegener in early Palaeozoic time the continents were grouped together to form one great continent which he called *Pangaea*. It was surrounded by a vast ocean called *Panthalassa*. This Pangaea was afterwards broken to pieces and then the parts of it drifted to form the present continental units. The drifting probably began in Silurian and continues even to-day. These separated parts of the continental units very nicely fit if put close together just like the teeth of two saws (c.f. the opposite shores of the Atlantic Ocean). The poles of the earth also migrated from place to place in the past.

One of the merits of this hypothesis is that it explains the mountain-building phenomenon nicely. Wegener believes in the isostatic equilibrium in the earth's crust. Wegener's idea of continental drifting can nicely explain—(i) variation of climate in the past, (ii) occurrence of identical fossils in separated parts of the earth, (iii) identical geological structures in separated parts of the earth and (iv) mountain-building.

Like Wegener *Daly* also accepts the initial united continent Pangaea, from which the present continental units drifted over the substratum which is elastic and viscous thereby producing the present oceans and continents. As a cause he advocates the forces of *gravitation*.

The other hypotheses like the *Radio-activity and the Thermal Cycle of Joly*, the idea of *Convection Currents in the Sub-crustal Region by Holmes* and the idea of *Contraction of the Earth due to Secular Cooling* have been discussed in the chapter on the mountains and their origin.

INDEX

T